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How to Calculate Effects of Tactical Low-Yield Enhanced-Radiation and Fission Warheads

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HOW TO CALCULATE EFFECTS OF TACTICAL LOW-YIELD ENHANCED-RADIATION AND FISSION WARHEADS

by

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ABSTRACT

In the last five years, a flood of literature, both in the US and abroad, has pointed out the pros and cons of effects from enhanced-radiation (ER) and fission warheads. While these publications often focus on numerical differences that can be quite large, they seldom tell the reader how the numerical values were obtained.

In this report, we assume pure-fusion, 50/50 fusion/fission, and pure-fission tactical weapons in yields from 0.5 to 10 kt. These assumptions make verification possible for all numerical values for the source as well as effects versus ground range. The effects considered are radiation, blast, and thermal. Several illustrations are presented in which we used various units to make the data more useful to the nontechnical reader.

In the literature, the main emphasis for ER tactical weapons has been the disabling effects on tank crews. The initial radiation dose rate inside the tank as well as that received by the crew from induced neutron activation inside the tank is numerically evaluated.

Soil-activation differences between fusion and fission weapons are mentioned.

I. INTRODUCTION

The purpose of this report is to present the basis for an assessment of fission versus hypothetical pure-fusion weapons at yields from 0.5 to 10 kt. Also presented are data for so-called enhanced-radiation (ER) devices that use both fission and fusion. For these types of weapons and their yields, we present a complete set of effects for prompt radiation, blast, and heat. The residual nuclear radiation, which is another significant effect, is not considered here because only airbursts with a proper height of burst (HOB) are considered. All numerical results are derived from first principles and the pure-fission and pure-fusion weapons represent limiting cases that permit assessment of limiting ranges for both intended lethal and unwanted collateral damage over the whole yield range. For this report, intended lethal damage is produced by prompt nuclear radiation. Collateral damage may be produced by any of the nuclear-weapon effects.

The 50% fission and 50% fusion data give ranges of a reasonable assumption for a weapon with fission and fusion components. Calculations have been made to determine the relative effects of nuclear explosions produced by

- D-T fusion,
- fission, and
- 50% D-T fusion plus 50% fission, referred to as 50/50.

The effects studied were nuclear radiation (rads), blast (psi), and thermal radiation (cal/cm^2) for yields from 0.5 to 10 kt. Results should be read assuming a 100-m HOB for yields up to 1 kt, and 200 m and 300 m for higher yields. For each of the three effects, plots of intensity per mole of neutrons versus ground range will be presented. In addition, plots were made of yield versus ground range for the following constant intensity values:

- 2×10^5, 16 000, and 50 rads;
- 5 and 2 psi; and
- 5 and 2 cal/cm^2.

For radiation, the value of 2×10^5 rads is representative of highly supra-lethal doses—16 000 rads produces about 8000 rads inside a tank, which means immediate incapacitation of the crew; 50 rads may be a reasonable estimate of a tolerable level for persons in the adjacent area. For blast, 5 psi produces serious casualties for persons in the adjacent area—2 psi is probably the lowest overpressure at which these casualties begin to occur. For heat, 5 cal/cm^2 produces second-degree burns on human skin—2 cal/cm^2 is the value for the onset of burn injuries.

Note that all these numbers for nuclear effects (lethality and collateral damage) are subject to rather large uncertainties and should be interpreted only as representative numbers for comparing different weapons. The following are some sources of these uncertainties. For weapons of the same design yield, a statistical variability of actual yield is produced. The transport of nuclear effects from an explosion to a given distance is inherently uncertain and also depends on terrain and weather conditions. Of course, additional uncertainties are introduced in judging human responses to the quoted levels of effects.

II. CONVERSION FACTORS

Before discussing our calculation methods, we list some of the conversion factors used in this study.

Nuclear Radiation*

1-kt D-T fusion: 1.48×10^{24} neutrons, 2.46 moles of neutrons.

1-kt fission: 0.25×10^{24} neutrons, 0.415 moles of neutrons.

Equivalent fission yield: fission yield + $16 \times$ fusion yield.

Blast Effects**

Equivalent fission yield: fission yield + $0.5 \times$ fusion yield.

Thermal Effects**

Equivalent fission yield: fission yield + $0.5 \times$ fusion yield.

III. CALCULATIONAL METHODS

For the nuclear radiation effects, we used the data reported by Sandmeier et al.,[1] which give the neutron and gamma-ray doses for a point source (in air) of 14-MeV and fission-spectrum neutrons at source heights of 100 and 300 m. In this study, we assumed an air-over-wet-ground interface and a detector height of 2.5 m above ground. Values for a 200-m source height were obtained by averaging the results for 100 and 300 m. Instead of treating the neutrons and gamma rays separately, we summed both components and consider total doses only. Because the calculations in Ref. 1 were normalized to one source neutron, the rads per mole of neutrons were easily computed. For the curves with yields as ordinates, we used the above conversion factors from yield to number of neutrons. Actually, we plotted curves of rads versus ground range for selected yields and read the ground ranges that corresponded to the specified doses. The curves showing the radiation effects are plotted in Figs. 1 through 10 (100-m HOB), 11 through 20 (200-m HOB), and 21 through 30 (300-m HOB). For reference, we include curves of rads versus ground range for selected yields. For 100-m HOB, see Figs. 3 through 6. The curves for 200 m are shown in Figs. 13 through 16, and for 300 m, in Figs. 23 through 26.

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*The number of D-T neutrons per kiloton of TNT can be computed as follows. In the D-T reaction, we obtain 1 neutron per 17.6 MeV of energy released. Based on an energy release of 10^{12} cal (2.6×10^{25} MeV) per kiloton of TNT, the number of 14-MeV neutrons per kiloton of TNT is 1.48×10^{24}. In the case of pure fission, we have taken 170 MeV as the prompt energy release per fission. As noted above, 2.6×10^{25} MeV per kiloton, we need 1.5×10^{23} fissions for 1 kt of TNT. Experiments with small fast critical assemblies of fully enriched uranium (Godiva) and plutonium (Jezebel) indicate an average leakage of 5/3 neutrons per fission. Thus, the leakage of 0.25×10^{24} fission neutrons is equivalent to 1 kt of TNT. The value 16 in the equivalent fission yield formula for fusion is obtained from $2.46/0.415 \times 2.7 = 16$. where 2.7 is the difference in effectiveness (rads) of a fusion neutron as compared to a fission neutron at 1000-m ground range.

**The number 0.5 in both the equivalent fission yield for blast and thermal for the fusion yield is obtained from

$D + T = n + \alpha + 17.58$ MeV,

KE of $n = 14.06$ MeV,

KE of $\alpha = 3.52$ MeV.

If 1/3 neutron energy is lost in the range of the fireball, the effective deposition energy = $3.52 + 14.06/3 = 8.2$ MeV, or 47% of total, which is near 50%.

The parameters required to evaluate blast effects were derived from data given by Glasstone.[2] Specifically, we used Fig. 3.73c from Ref. 2 to read peak overpressures on the ground for a given burst height from a 1-kt fission burst. For yields other than 1 kt, we used the scaling relationship

$$D = D_1 \times W^{1/3} \quad ,$$

where, for a given peak overpressure, D is the slant range for W kt, D_1 is the distance (slant range) for 1 kt, and W is the fission yield in kilotons. Curves showing blast effects are displayed in Figs. 7 and 8 (100-m HOB), Figs. 17 and 18 (200-m HOB), and Figs. 27 and 28 (300-m HOB).

Finally, we computed thermal radiation effects using Eq. (7.96.2) given in Ref. 2:

$$Q(\text{cal/cm}^2) = 10^{12}\, f\, W\, \tau/(4\pi D^2) \quad ,$$

where

Q = energy received per unit area normal to direction of propagation at a distance D from the explosion,

f = thermal partition, and

τ = transmittance.

From Table 7.88 of Ref. 2, f = 0.35 for air bursts up to 4572-m (15 000 feet). From Fig. 7.98 (Ref. 2), we note that for our assumed burst heights and ground ranges, τ is about 0.9 on a typical clear day. We have used a value of 0.8 for τ, corresponding to lower visibility conditions. If D is expressed in meters, and for the values assumed for f and τ, the above formula becomes

$$Q(\text{cal/cm}^2) = 2.23 \times 10^6\, W/D^2 \quad .$$

Effects of thermal radiation are shown in Figs. 9 and 10 (100-m HOB), Figs. 19 and 20 (200-m HOB), and Figs. 29 and 30 (300-m HOB).

To place some of the large amount of presented data in some sort of perspective, we have summarized in Table I the distances at which specified effects occur for 0.5-, 1-, 5-, and 10-kt weapons. To illustrate the use of Table I, we observe that a 1-kt fusion weapon would give 16 000 rads at a ground range of 820 m for a 100-m HOB. However, a 10-kt fission weapon is required to achieve the same dose at about the same ground range for a 200-m HOB. The differences in HOB account for some of the discontinuities apparent in the results presented in Fig. 1. In contrast, the 5-psi values for the 1-kt 50/50 and 10-kt fission weapons are 500 and 1350 m, respectively. Similar behavior is observed for the thermal radiation effects. Note that the $W^{1/3}$ scaling for blast effects does not hold in going from 1 kt to 10 kt. All values in Figs. 1 through 30 and in Table I have significant error bars that vary from case to case; therefore, Table I is best used in comparing one kind of weapon to another.

IV. DOSE TO TANK CREW FROM INITIAL NUCLEAR RADIATION AND NEUTRON INDUCED RADIOACTIVITY IN THE TANK ARMOR

For tactical-nuclear-weapons applications it is important to assess the protection provided to tank crew members in an ER or fission-weapon environment. Here we discuss the protection that armored vehicles provide.

A. Initial Nuclear Radiation

Crew protection against initial nuclear radiation is expressed in terms of a "transmission factor" (TF). TF is equal to the ratio of doses inside and outside the vehicle. We can multiply the TF by the radiation dose outside the tank and obtain the prompt dose inside the tank. This applies to all the radiation curves (Figs. 3-6, 13-16, 23-26) and to the radiation numbers in Table I. For a representative medium tank with 15-cm (6-in.) chrome-nickel steel armor, we get

$$\begin{aligned} TF &= 0.5 \text{ (fusion)} \\ &= 0.6 \text{ (fission)} \quad . \end{aligned}$$

These values are very similar to the TF values presented in a recent publication[3] for Soviet and US medium tanks or assault vehicles and armored personnel carriers.

B. Neutron Induced Gamma Radioactivity in Tank Armor

To find the neutron induced radioactivity in the tank armor itself, we obtained the time-dependent dose inside a tank at ground zero per kiloton for both fusion and fission weapons exploded at 200-m HOB. The dose rates in rad/h are shown in Fig. 31. The dose rate at $t = 0^+$ is 587 rad/h for fusion and 24 rad/h for fission. This difference is partially accounted for by the much larger number of neutrons (about 6 times more) in 1 kt of fusion as compared with 1 kt of fission.

If we integrate the dose rate from $t = 0^+$ to 1000 h, we get for the radiation dose to the crew

$$800 \text{ rad } 0^+ \leq t \leq 1000 \text{ h (fusion) and}$$
$$51 \text{ rad } 0^+ \leq t \leq 1000 \text{ h (fission).}$$

Of course, at time $t = 0^+$, the crew inside the tank receives the initial prompt dose from 1 kt, which is 2 to 3 orders of magnitude higher (and lethal indeed) than the above-quoted dose from induced radiation in the armor.

At time $t = 1$ h, we again integrate to 1000 h, and the radiation dose impinging on the crew is

$$500 \text{ rad } 1^+ \leq t \leq 1000 \text{ h (fusion) and}$$
$$35 \text{ rad } 1^+ \leq t \leq 1000 \text{ h (fission).}$$

These calculations on radioactivity in tanks were carried out for homogeneous tank armor. The latest models of both US and Soviet tanks are protected by laminated armor whose composition is classified.

V. RESIDUAL NUCLEAR RADIATION

Residual radiation includes both fallout and neutron induced radiation in the soil. Fallout radiation consists principally of gamma rays emitted from fission products that have been deposited on the ground after a surface or near-surface nuclear burst. For the airbursts considered in this report, local fallout is negligible.

Induced ground activity was addressed by Sandmeier and Hansen in a previous publication.[4] On a per-neutron basis, ground activity produced by a fusion device is, at 1 day, 1.5 times that produced by a fission device. On a per-kiloton basis, this factor increases to 8.4. At 1 year, the respective factors are 0.74 and 4.4. In Ref. 4, the authors conclude that neutron induced ground radioactivity will not be an important consideration in the airburst employment of low-yield (less than 10 kt) tactical nuclear weapons.

ACKNOWLEDGMENT

We are grateful to our Los Alamos colleague, R. Sandoval, for his many pertinent discussions. He encouraged us to make our data more accessible to the public. His continued support and encouragement have been very helpful in our preparation of this report.

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2. Samuel Glasstone and Philip J. Dolan, ***The Effects of Nuclear Weapons***, Third edition, United States Department of Defense and United States Department of Energy (1977).

3. Charles N. Davidson, "Armored Vehicle Shielding Against Radiation," Nuclear Notes Number 8, US Army Nuclear and Chemical Agency, Fort Belvoir, VA 22060 (May 1979).

4. H. A. Sandmeier and G. E. Hansen, "Neutron-Induced Ground Activities from Small Thermonuclear and Fission Weapons," Los Alamos Scientific Laboratory memorandum TD-3 (April 12, 1972).

TABLE I. Ground Ranges (m) for Selected Radiation, Blast, and Thermal Effects for D-T Fusion, 50/50, and Fission Weapons

	Height of Burst = 100 m			Height of Burst = 200 m			Height of Burst = 300 m		
	Fusion	50/50	Fission	Fusion	50/50	Fission	Fusion	50/50	Fission
Radiation									
16 000 rads									
0.5 kt	710	610	390	700	600	330	680	560	240
1.0	820	710	475	810	710	440	810	690	370
5.0	---	---	—	1080	980	690	1110	980	670
10.0	---	---	—	1190	1090	800	1240	1110	800
50 rads									
0.5 kt	1700	1600	1200	1650	1550	1220	1770	1650	1280
1.0	1860	1760	1310	1750	1650	1350	1900	1790	1440
5.0	---	---	—	2000	1900	1640	2210	2100	1810
10.0	---	—	—	2100	2000	1760	2340	2230	1980
Blast									
5 psi									
0.5 kt	340	390	430	340	410	460	370	450	510
1.0	430	500	550	460	540	600	510	610	690
5.0	---	---	—	830	960	1060	970	1130	1250
10.0	---	---	—	1060	1220	1350	1250	1440	1590
2 psi									
0.5 kt	610	700	770	700	800	890	760	890	990
1.0	770	890	980	890	1020	1130	990	1140	1270
5.0	---	---	—	1540	1770	1950	1740	1990	2200
10.0	---	---	—	1950	2230	2400	2200	2470	2650
Thermal									
5 cal/cm^2									
0.5 kt	320	400	460	270	370	430	150	280	370
1.0	460	570	660	430	540	640	370	500	600
5.0	---	—	—	1040	1280	1480	1010	1260	1470
10.0	---	—	—	1480	1820	2100	1470	1810	2090
2 cal/cm^2									
0.5 kt	520	640	740	490	610	720	440	570	680
1.0	740	910	1050	720	890	1040	680	860	1010
5.0	---	---	—	1660	2040	2350	1640	2020	2340
10.0	---	---	—	2350	2880	3330	2340	2880	3330

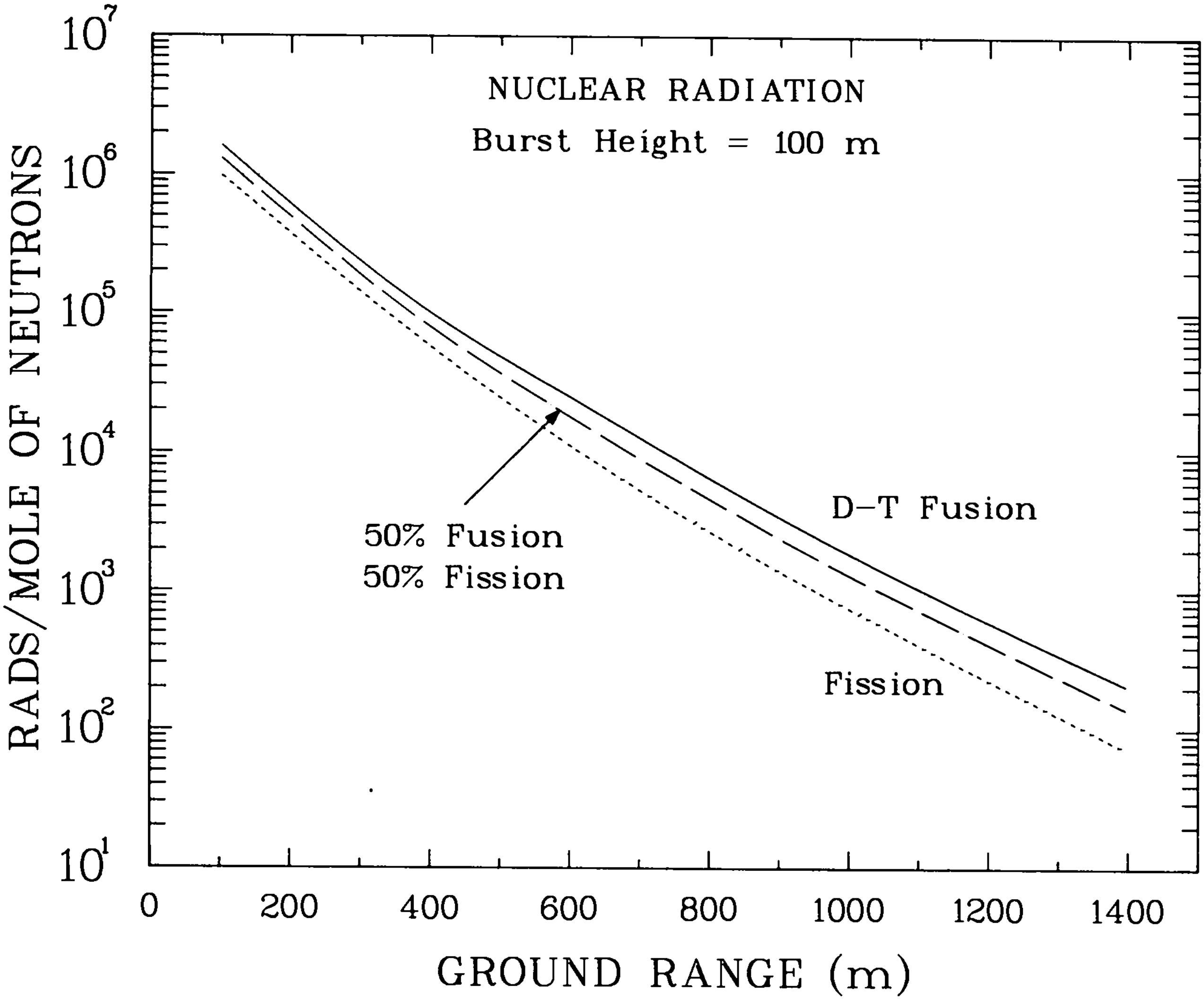

Fig. 1. Rads per mole of neutrons vs ground range. Burst height = 100 m. Fusion, fission, and fusion/fission (50/50) weapons.

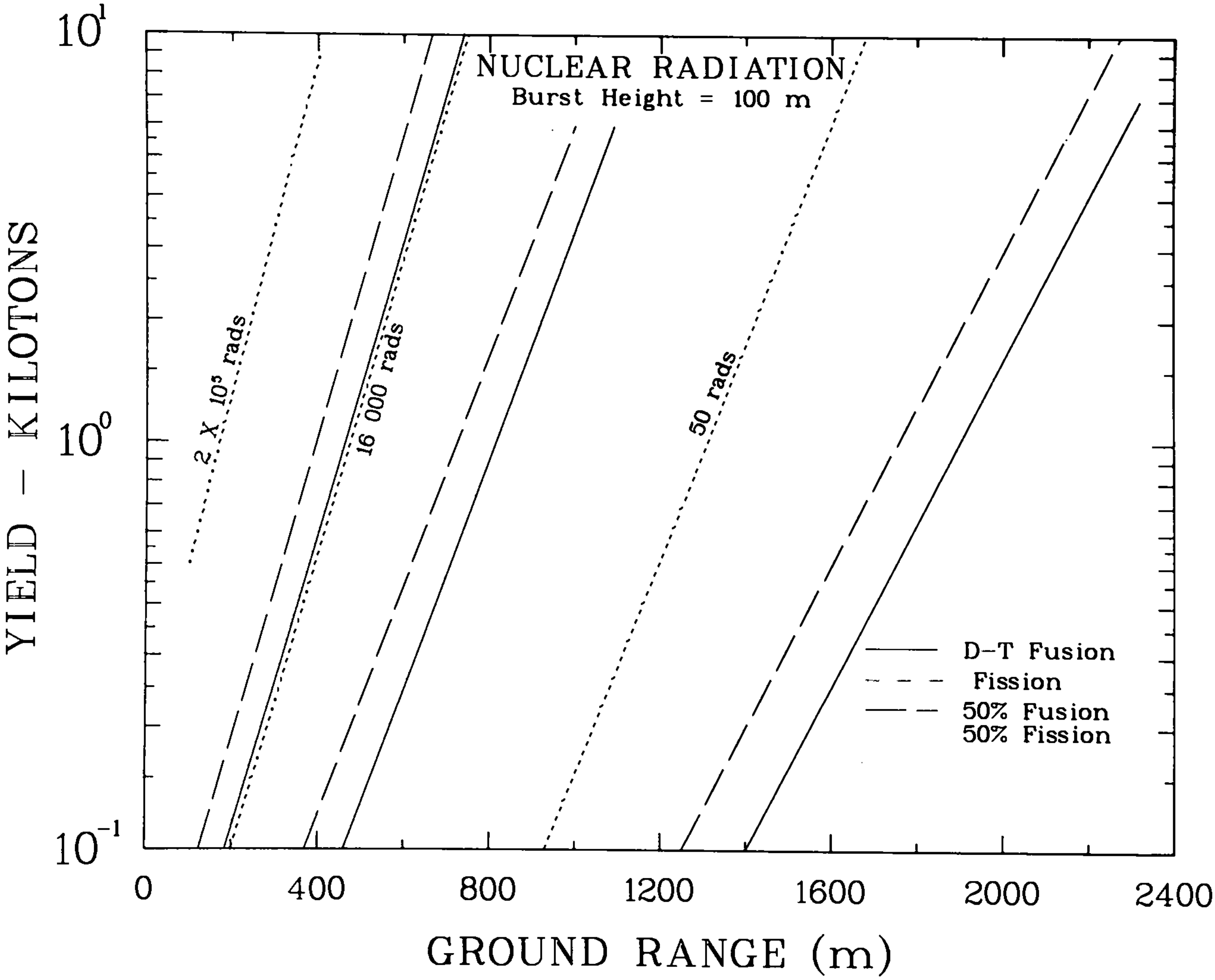

Fig. 2. Yield vs ground range for 50, 16 000, and 2×10^5 rads. Burst height = 100 m. Fusion, fission, and fusion/fission (50/50) weapons.

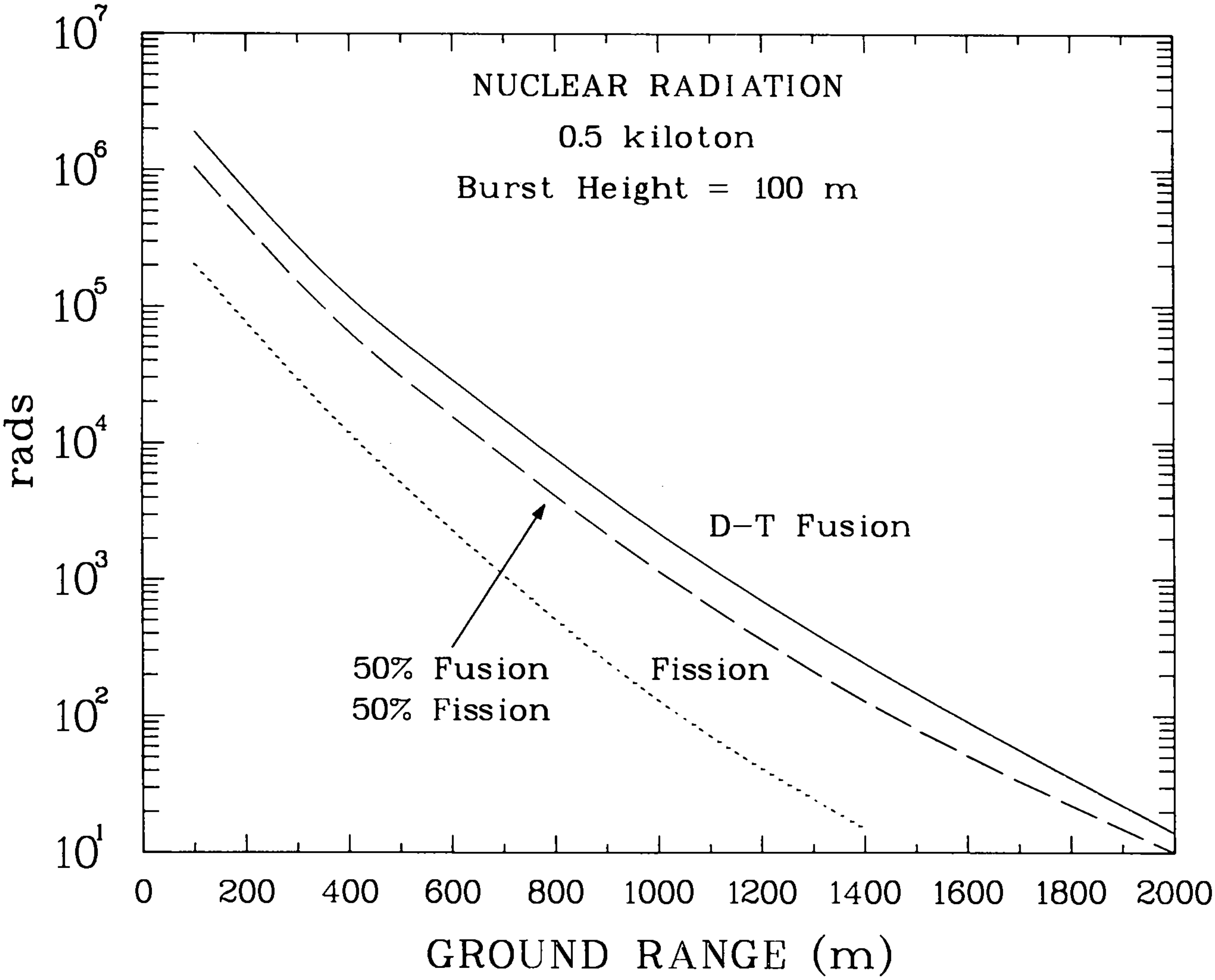

Fig. 3. Rads vs ground range for 0.5-kt fusion, fission, and fusion/fission (50/50) weapons. Burst height = 100 m.

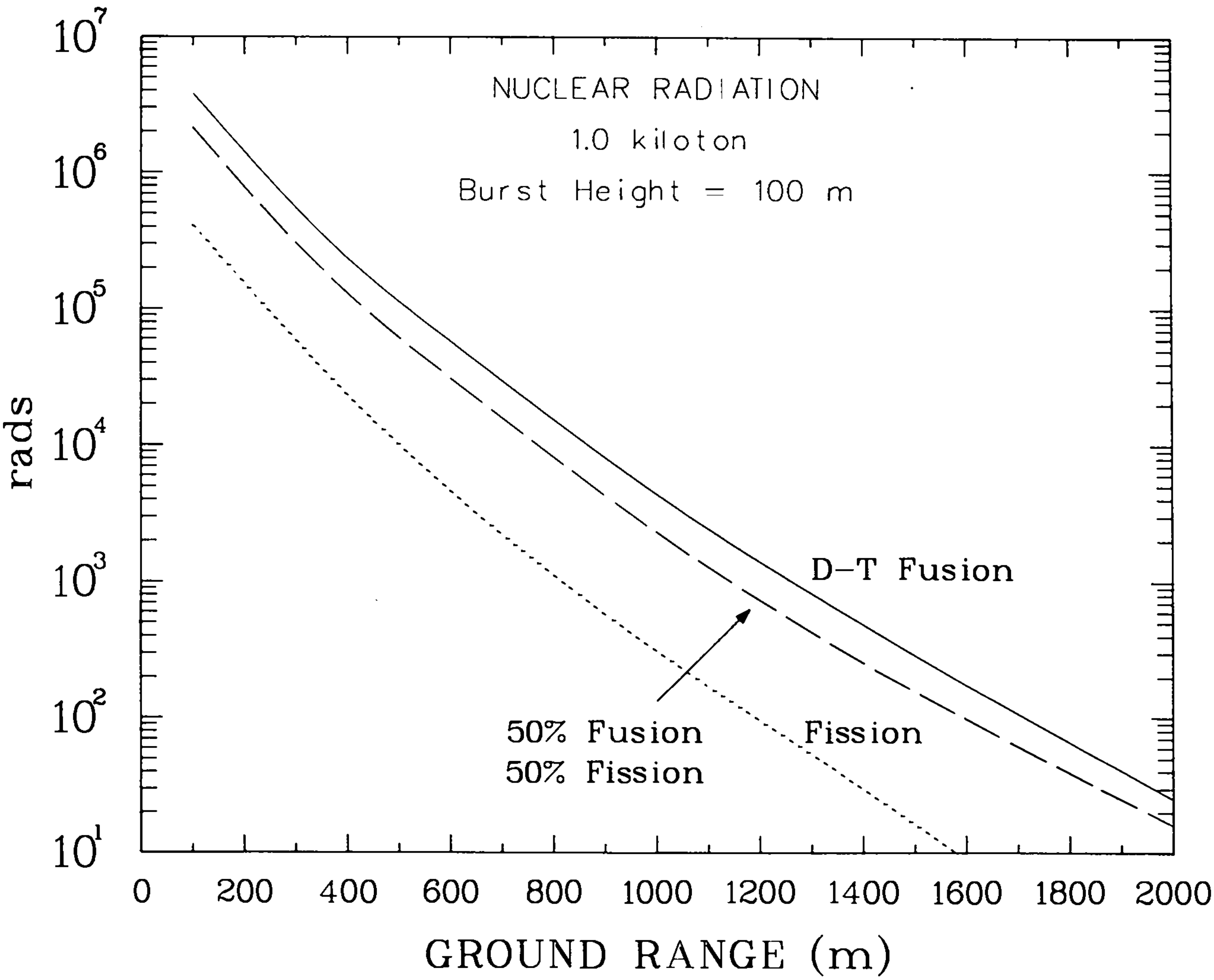

Fig. 4. Rads vs ground range for 1.0-kt fusion, fission, and fusion/fission (50/50) weapons. Burst height = 100 m.

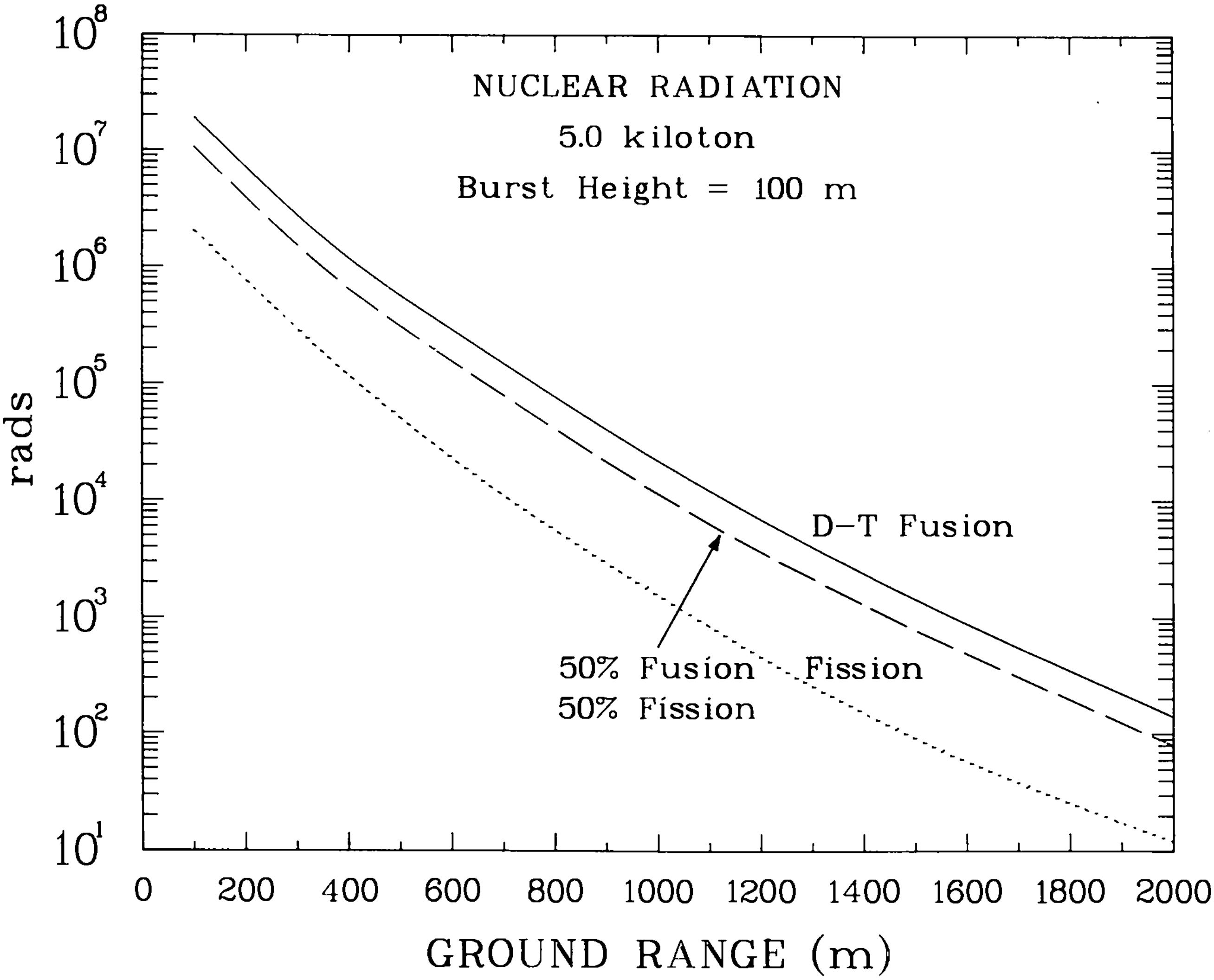

Fig. 5. Rads vs ground range for 5.0-kt fusion, fission, and fusion/fission (50/50) weapons. Burst height = 100 m.

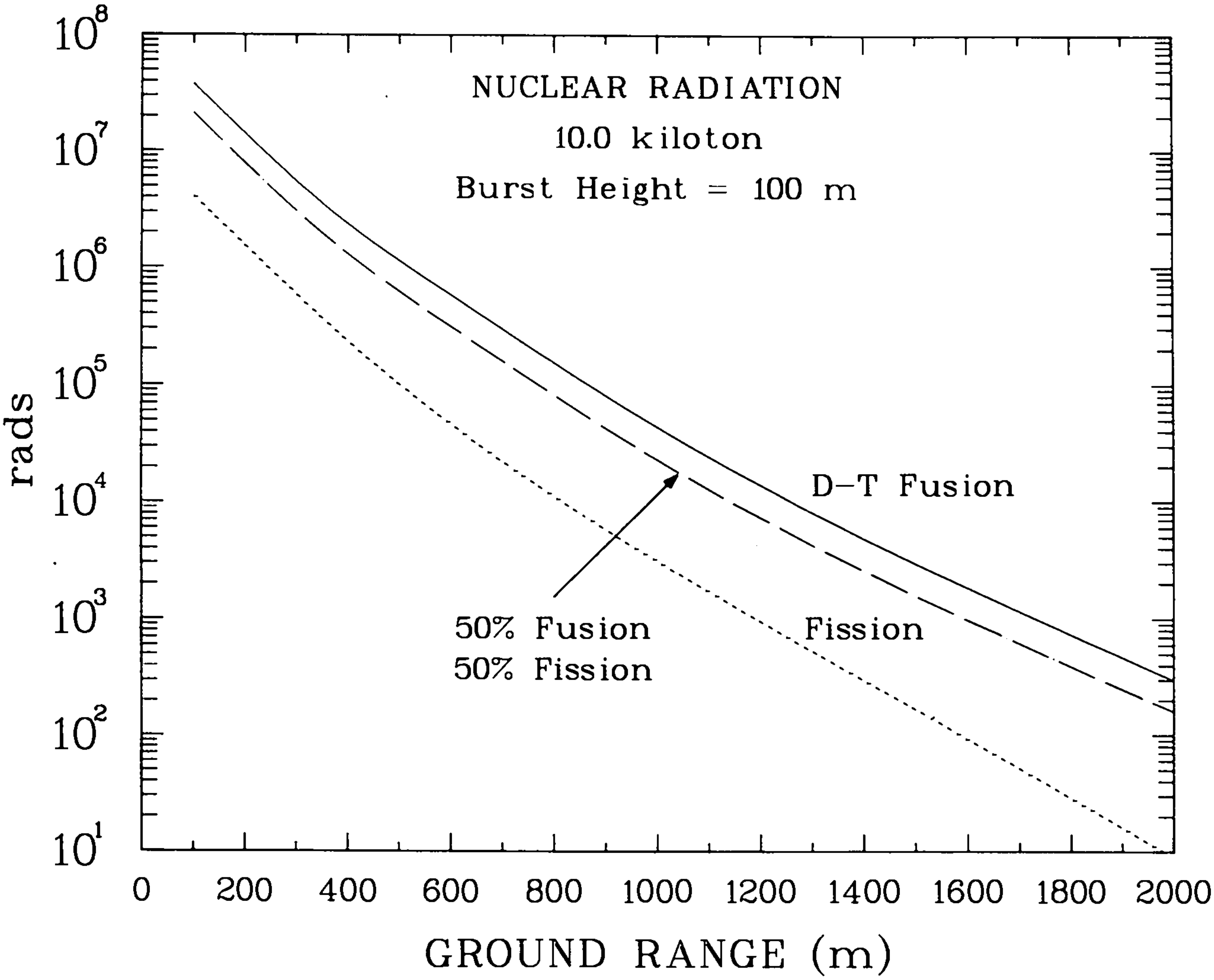

Fig. 6. Rads vs ground range for 10.0-kt fusion, fission, and fusion/fission (50/50) weapons. Burst height = 100 m.

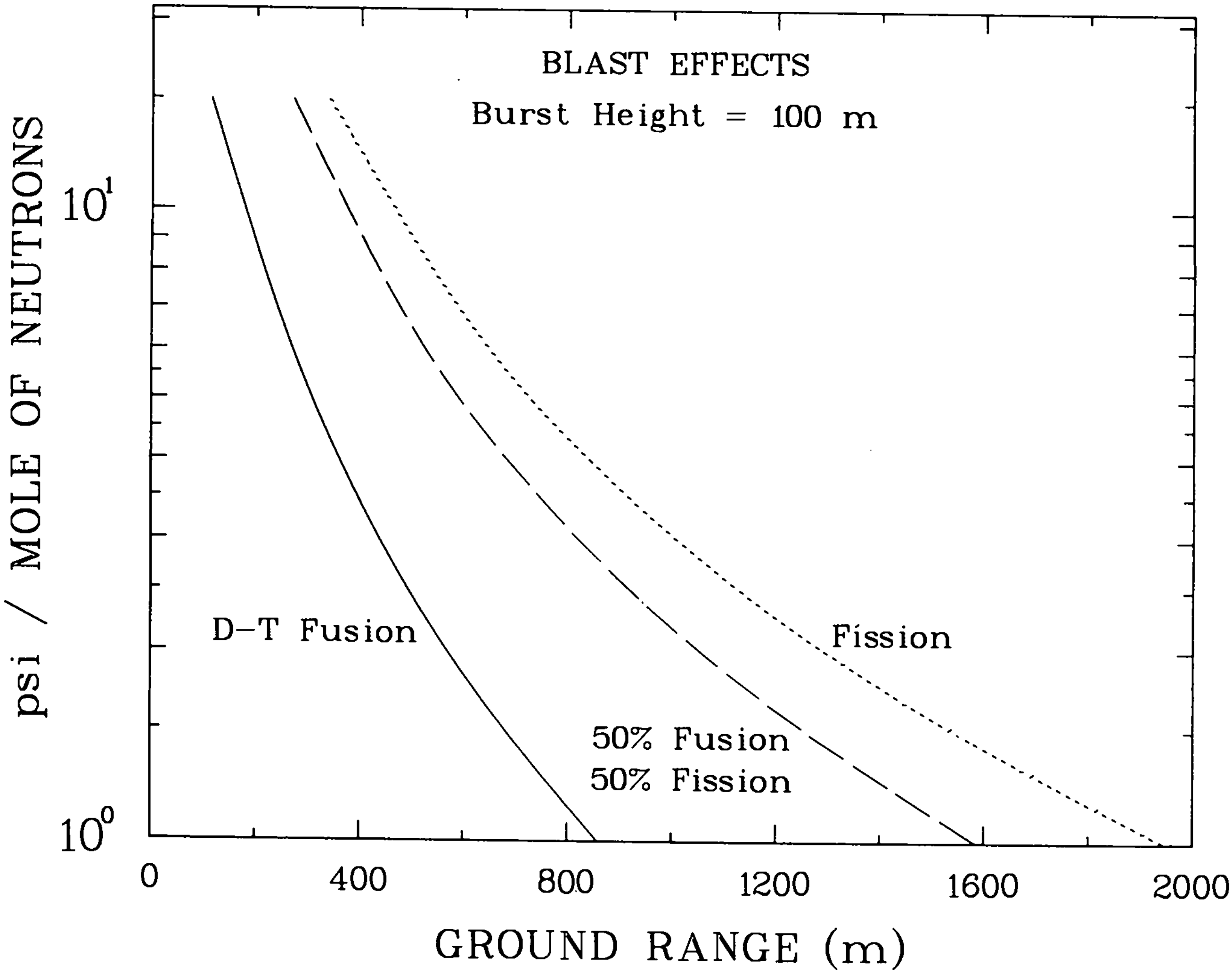

Fig. 7. Overpressure (psi) per mole of neutrons vs ground range. Burst height = 100 m. Fusion, fission, and fusion/fission (50/50) weapons.

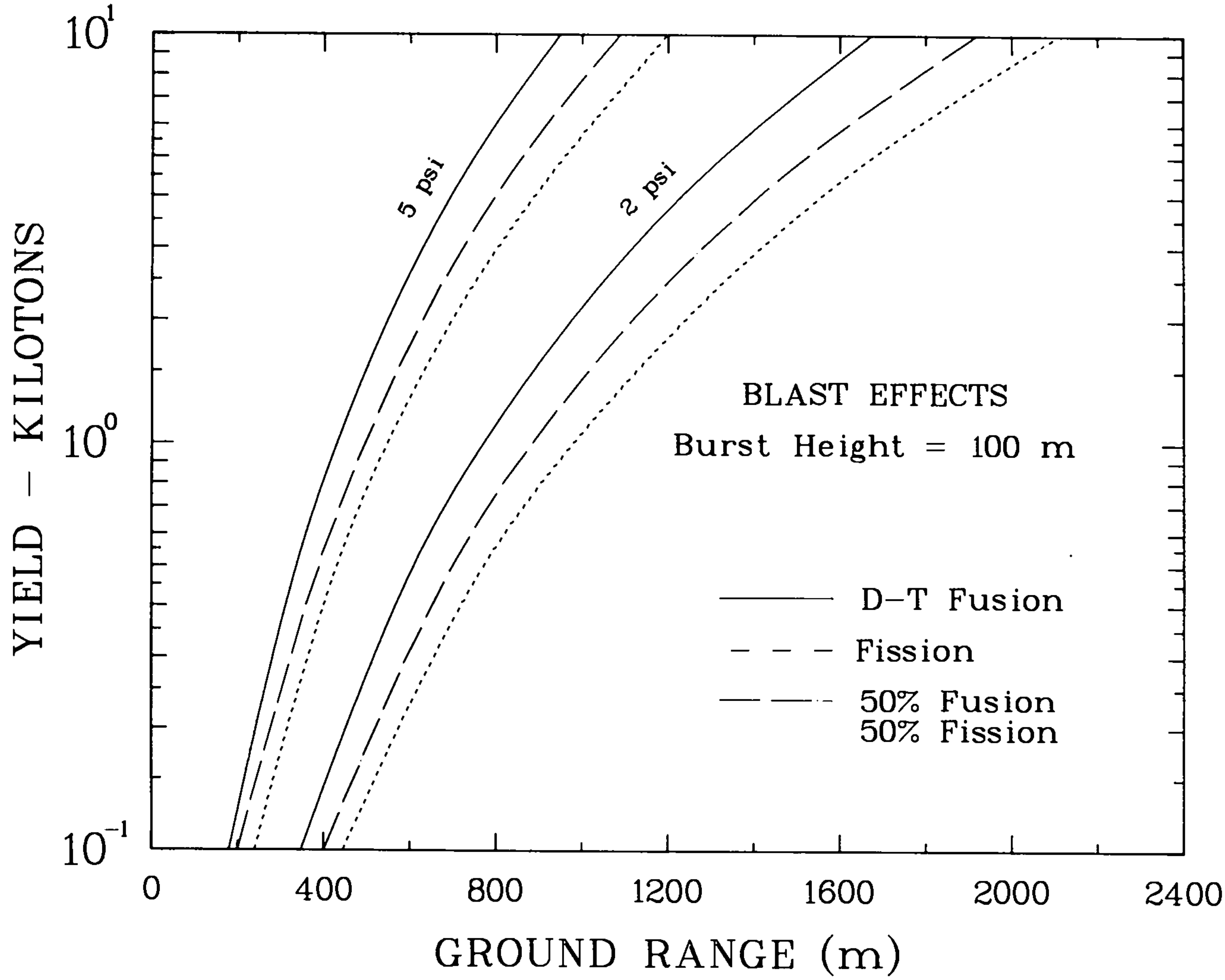

Fig. 8. Yield vs ground range for 2- and 5-psi overpressures. Burst height = 100 m. Fusion, fission, and fusion/fission (50/50) weapons.

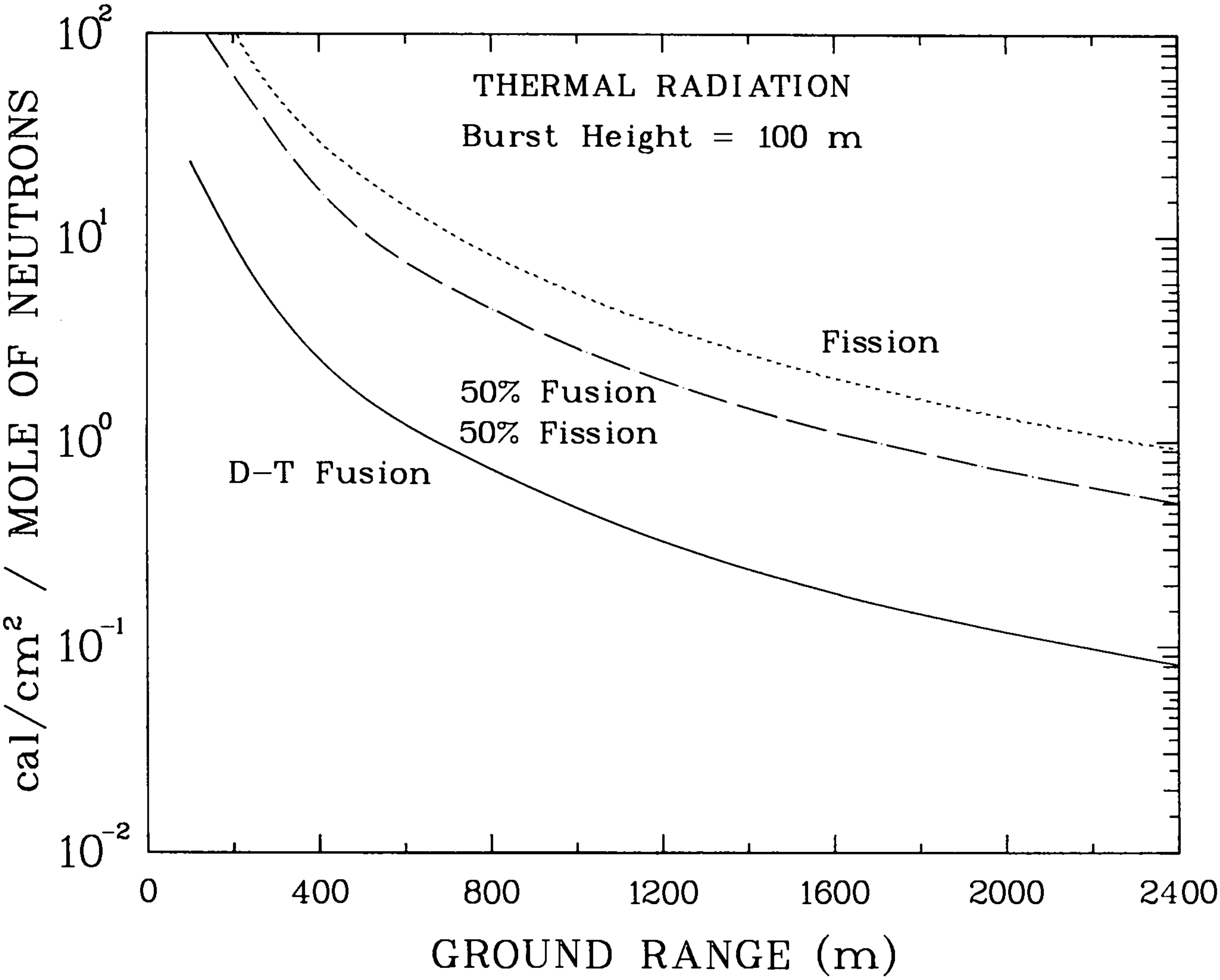

Fig. 9. Thermal radiation per mole of neutrons vs ground range. Burst height = 100 m. Fusion, fission, and fusion/fission (50/50) weapons.

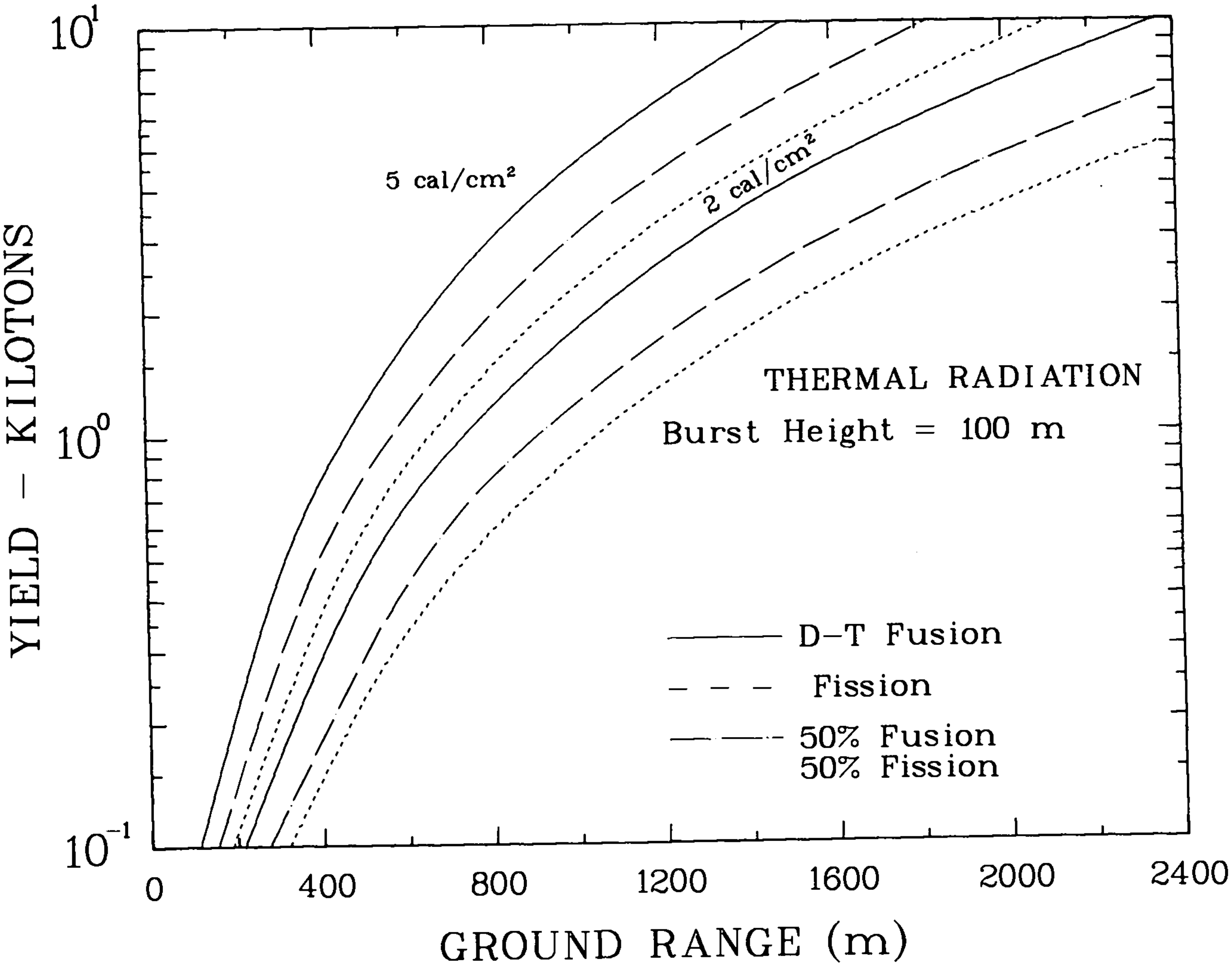

Fig. 10. Yield vs ground range for 2 and 5 cal/cm^2. Burst height = 100 m. Fusion, fission, and fusion/fission (50/50) weapons.

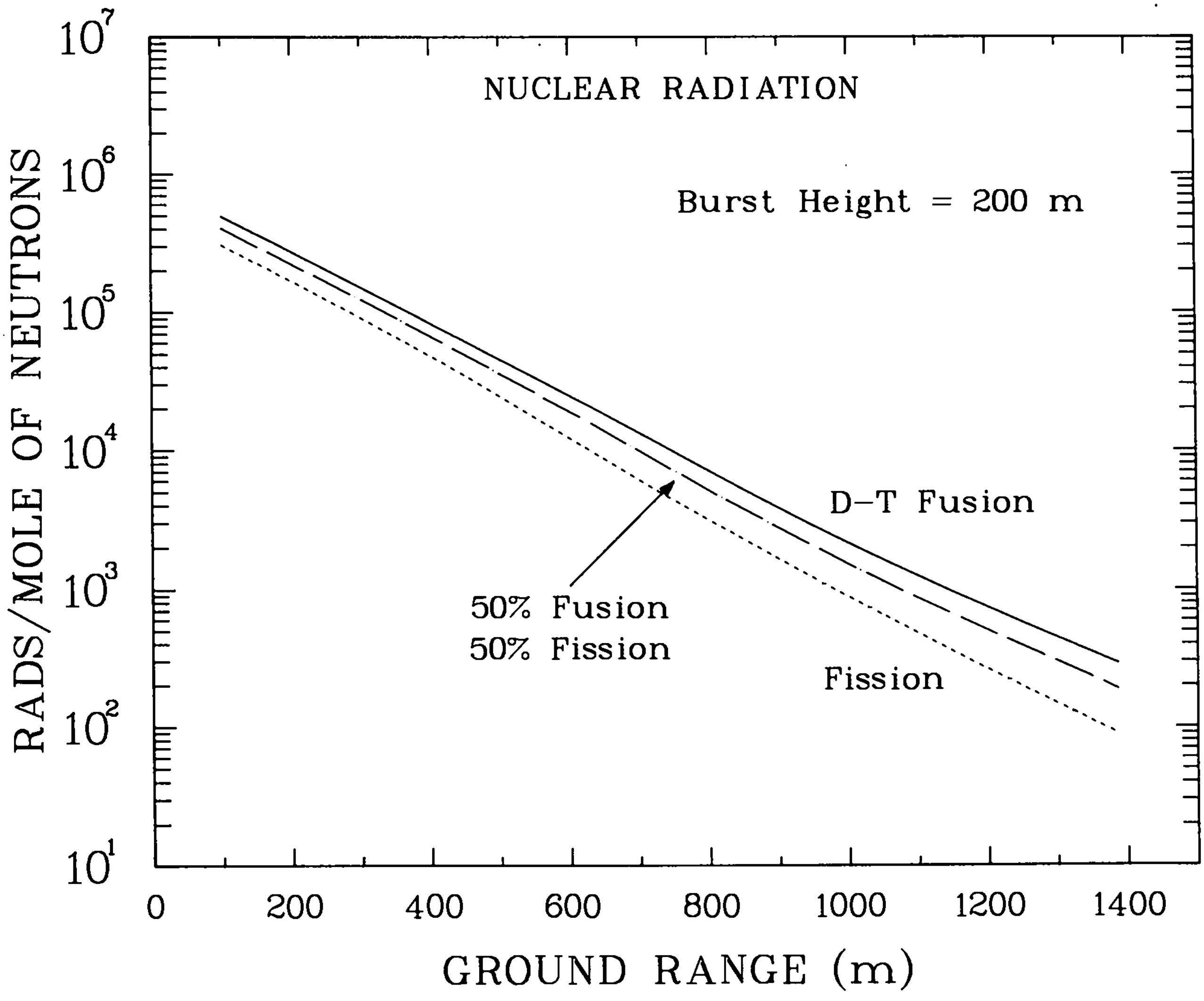

Fig. 11. Rads per mole of neutrons vs ground range. Burst height = 200 m. Fusion, fission, and fusion/fission (50/50) weapons.

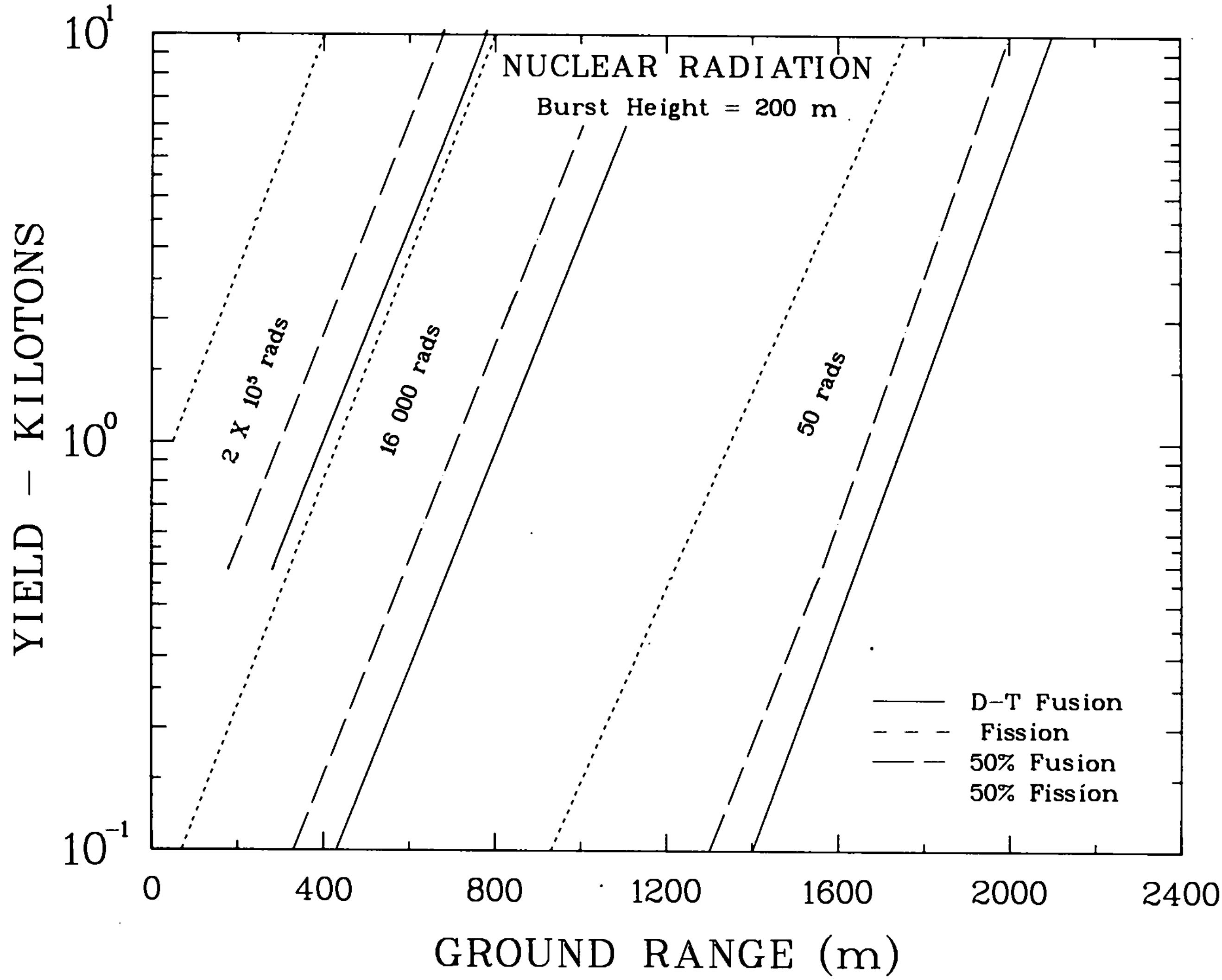

Fig. 12. Yield vs ground range for 50, 16 000, and 2×10^5 rads. Burst height = 200 m. Fusion, fission, and fusion/fission (50/50) weapons.

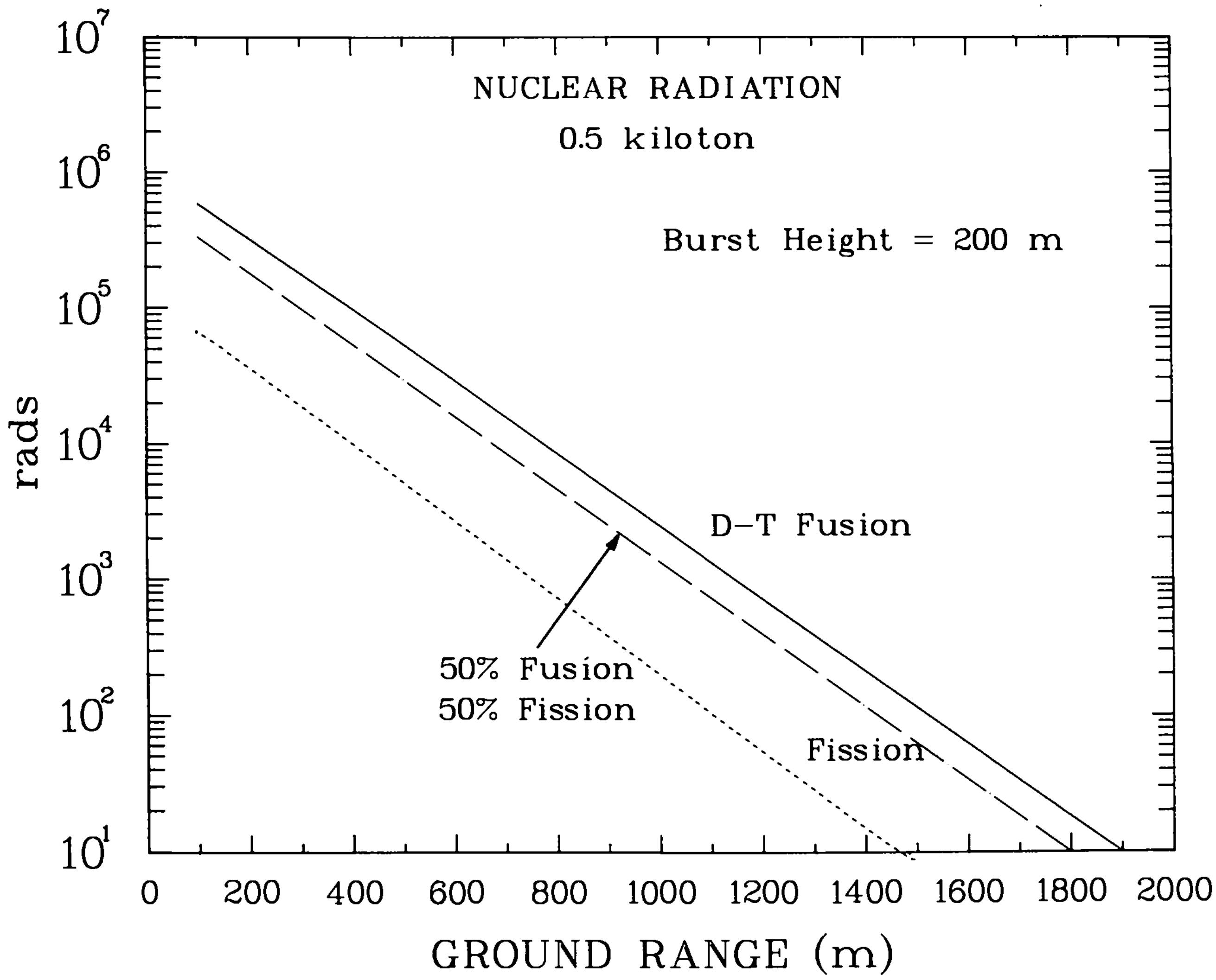

Fig. 13. Rads vs ground range for 0.5-kt fusion, fission, and fusion/fission (50/50) weapons. Burst height = 200 m.

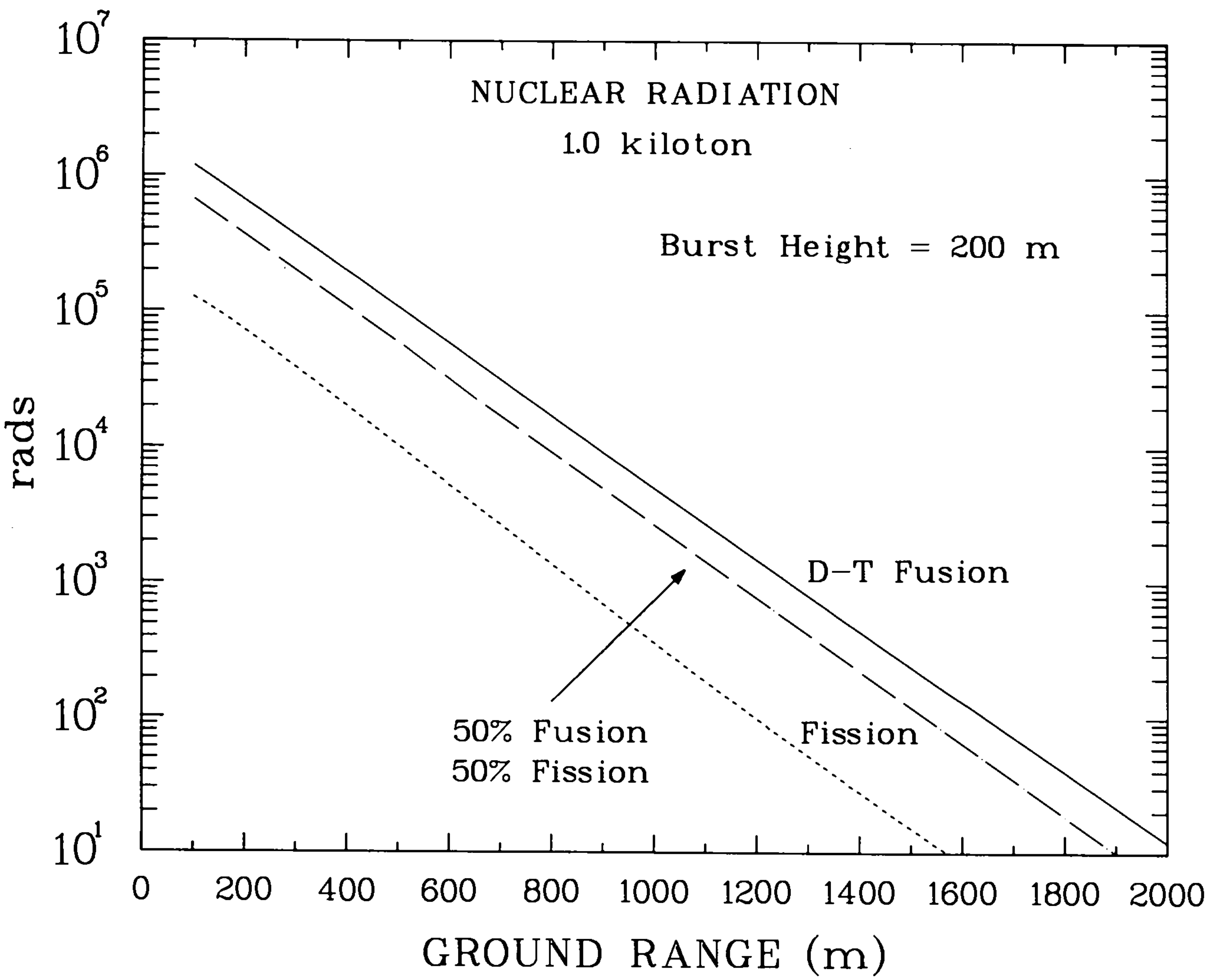

Fig. 14. Rads vs ground range for 1.0-kt fusion, fission, and fusion/fission (50/50) weapons. Burst height = 200 m.

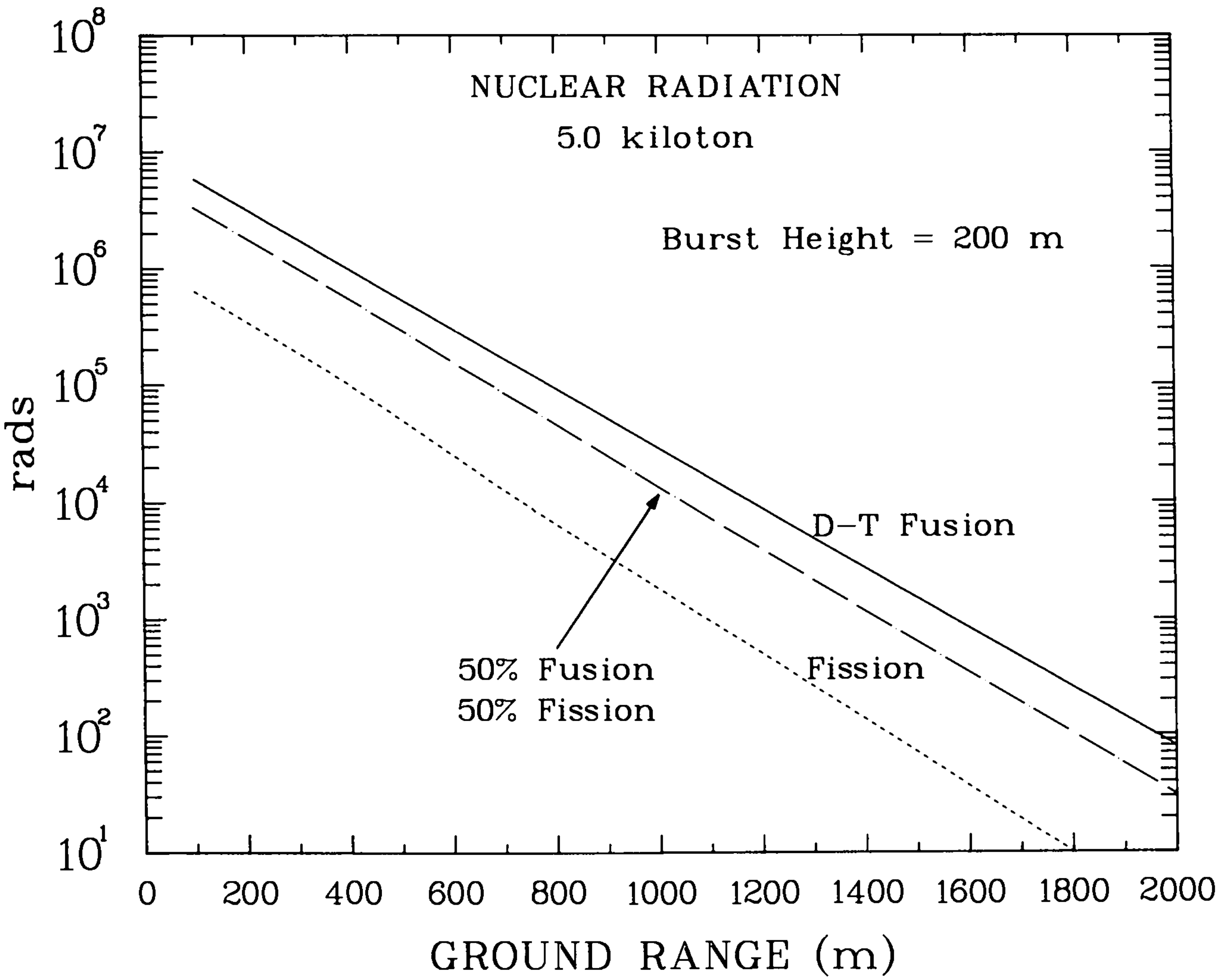

Fig. 15. Rads vs ground range for 5.0-kt fusion, fission, and fusion/fission (50/50) weapons. Burst height = 200 m.

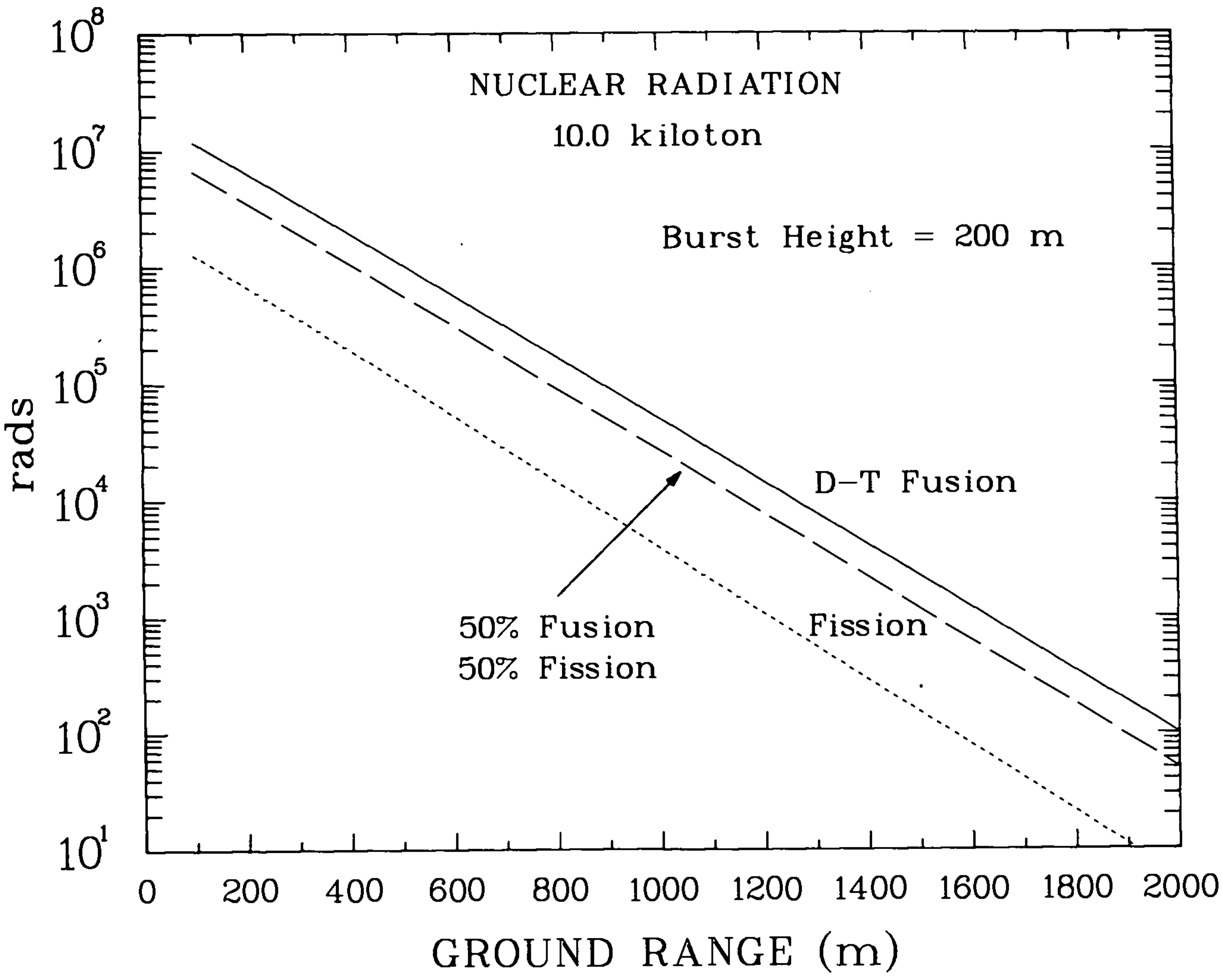

Fig. 16. Rads vs ground range for 10.0-kt fusion, fission, and fusion/fission (50/50) weapons. Burst height = 200 m.

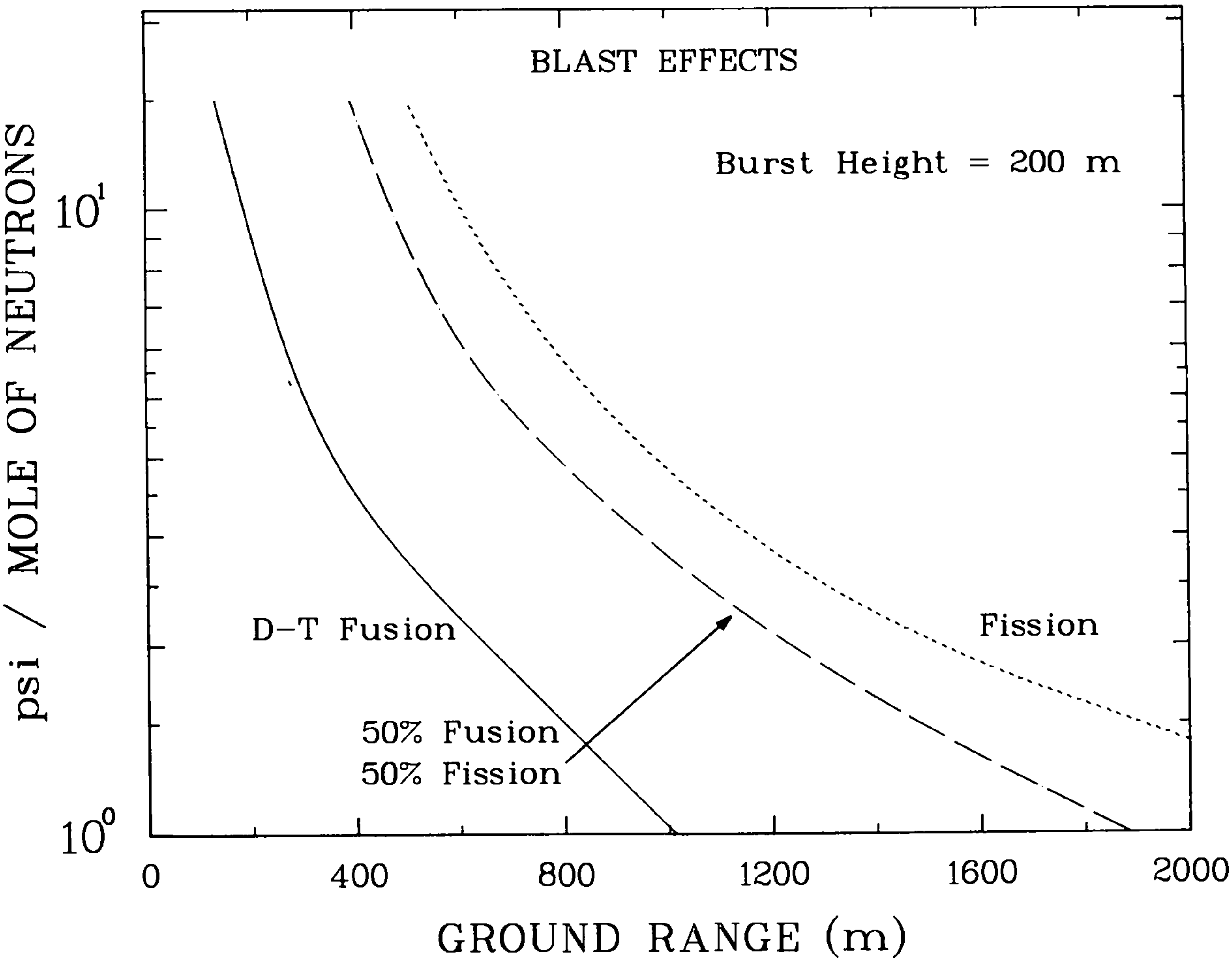

Fig. 17. Overpressure (psi) per mole of neutrons vs ground range. Burst height = 200 m. Fusion, fission, and fusion/fission (50/50) weapons.

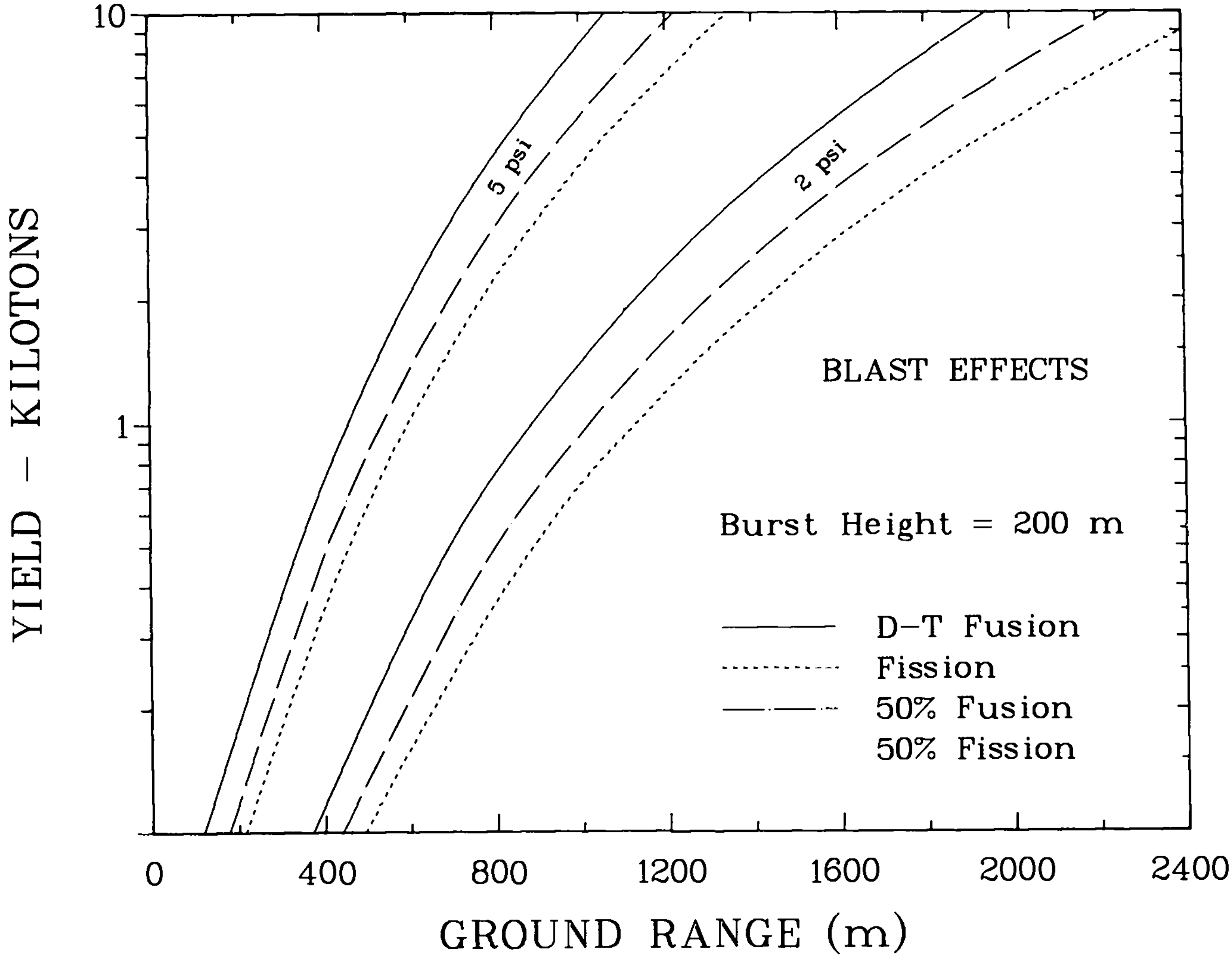

Fig. 18. Yield vs ground range for 2- and 5-psi overpressures. Burst height = 200 m. Fusion, fission, and fusion/fission (50/50) weapons.

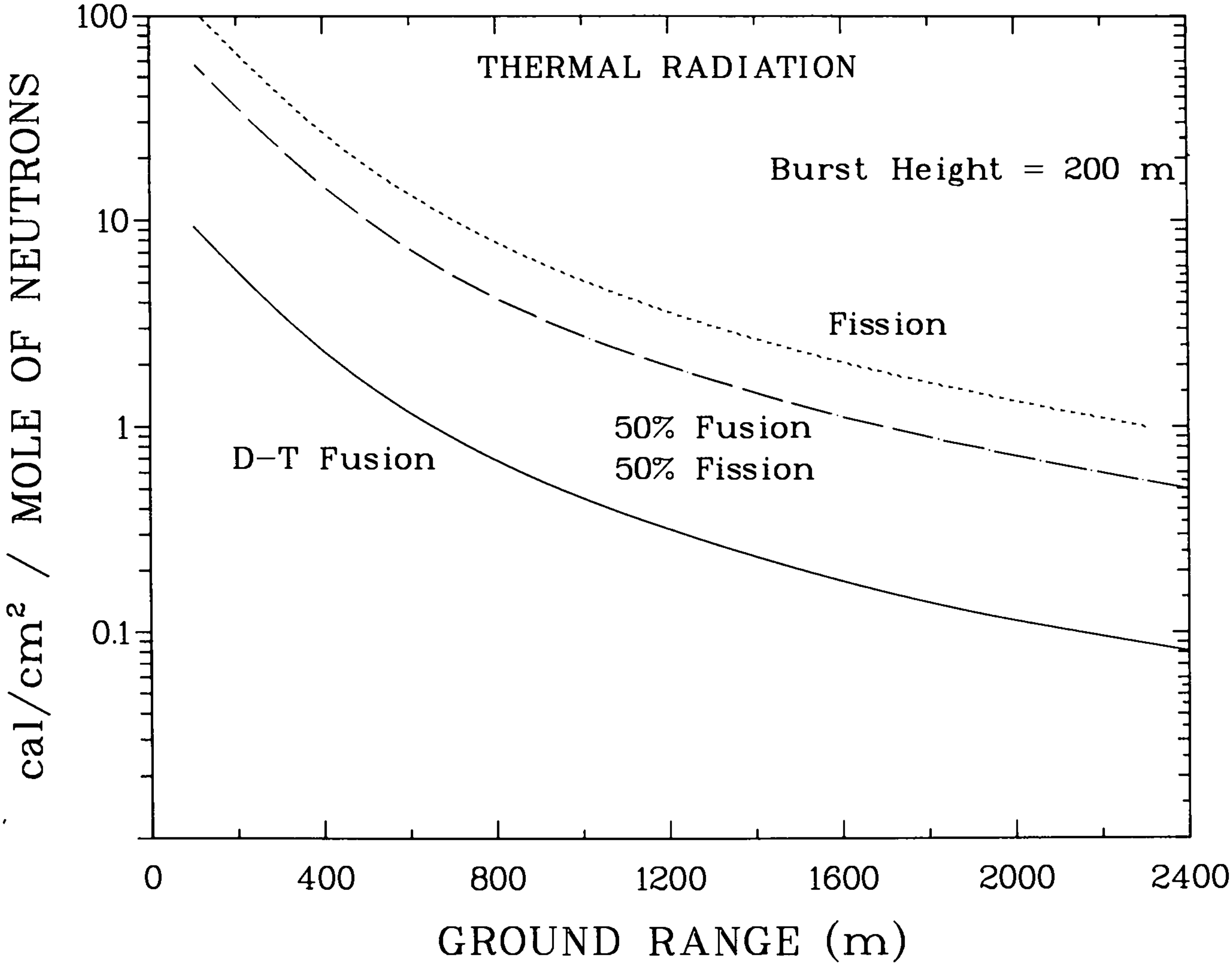

Fig. 19. Thermal radiation per mole of neutrons vs ground range. Burst height = 200 m. Fusion, fission, and fusion/fission (50/50) weapons.

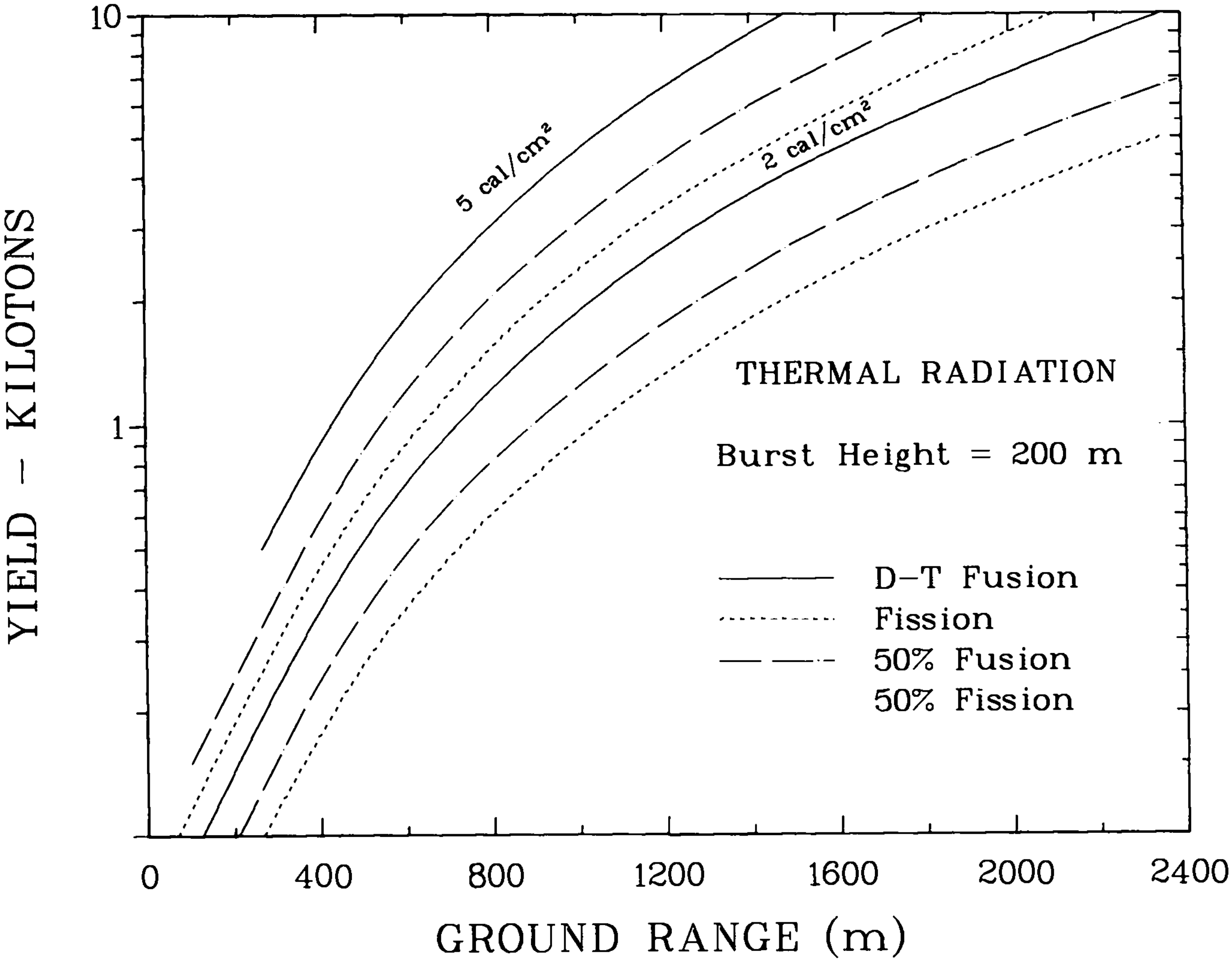

Fig. 20. Yield vs ground range for 2 and 5 cal/cm^2. Burst height = 200 m. Fusion, fission, and fusion/fission (50/50) weapons.

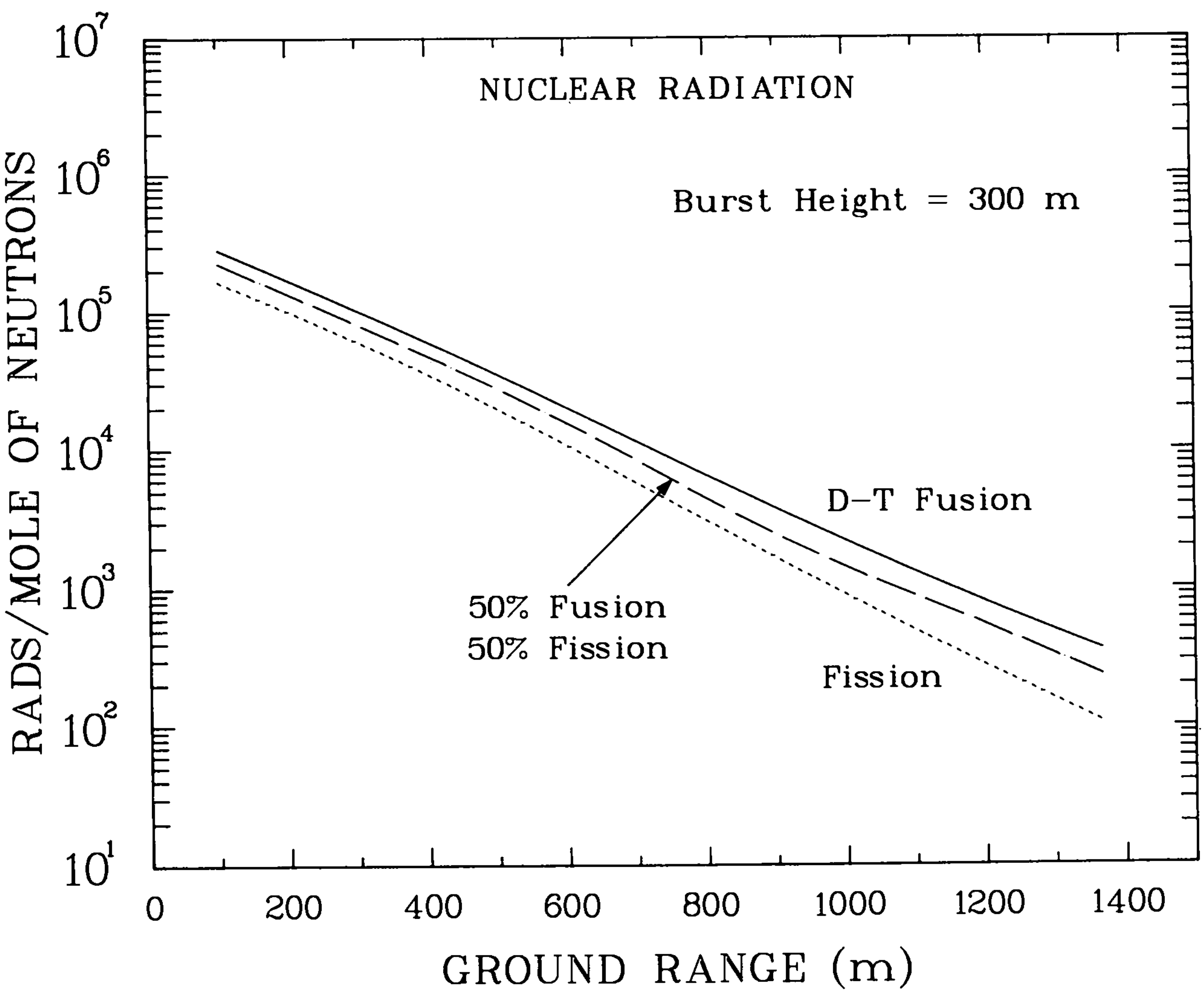

Fig. 21. Rads per mole of neutrons vs ground range. Burst height = 300 m. Fusion, fission, and fusion/fission (50/50) weapons.

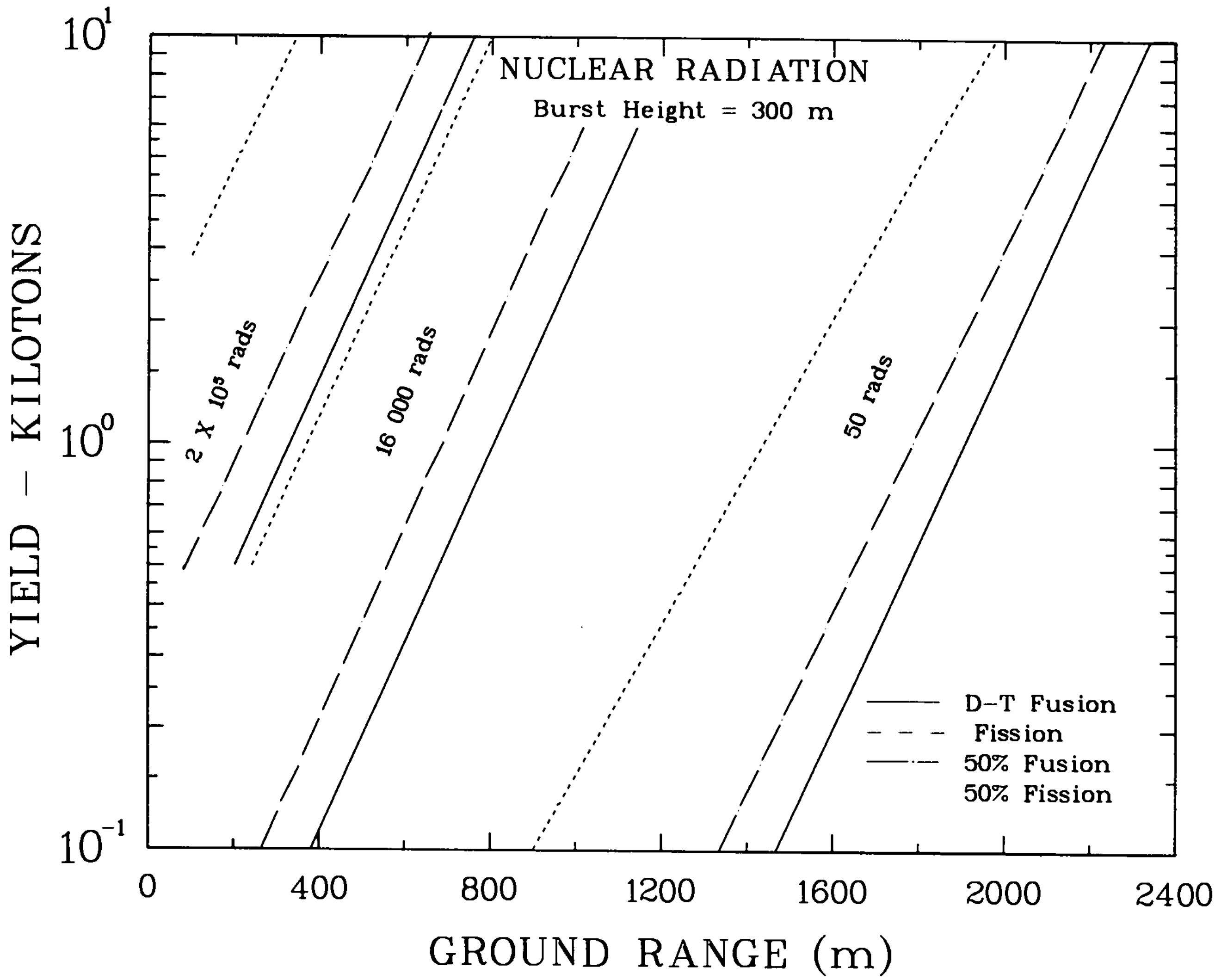

Fig. 22. Yield vs ground range for 50, 16 000, and 2×10^5 rads. Burst height = 300 m. Fusion, fission, and fusion/fission (50/50) weapons.

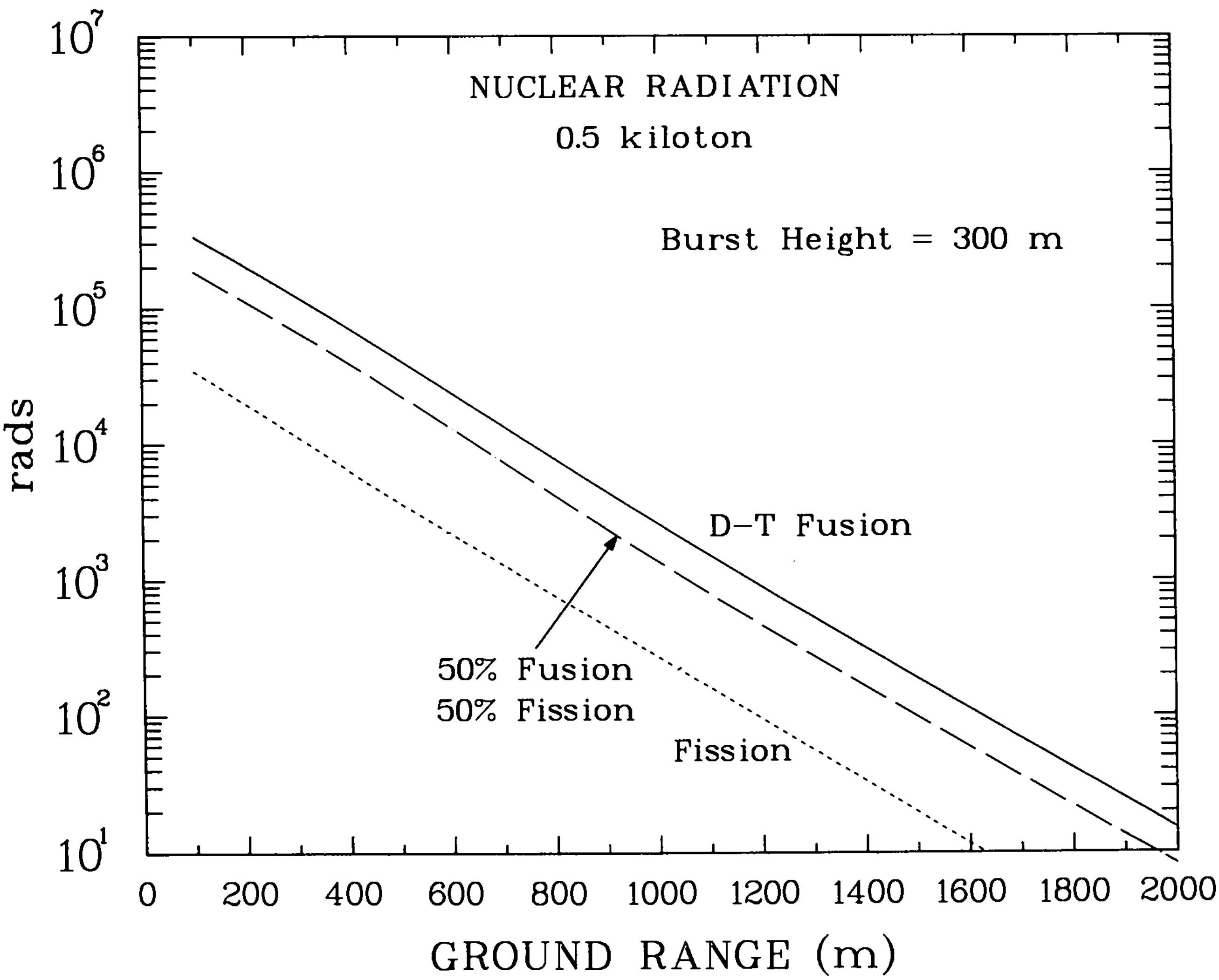

Fig. 23. Rads vs ground range for 0.5-kt fusion, fission, and fusion/fission (50/50) weapons. Burst height = 300 m.

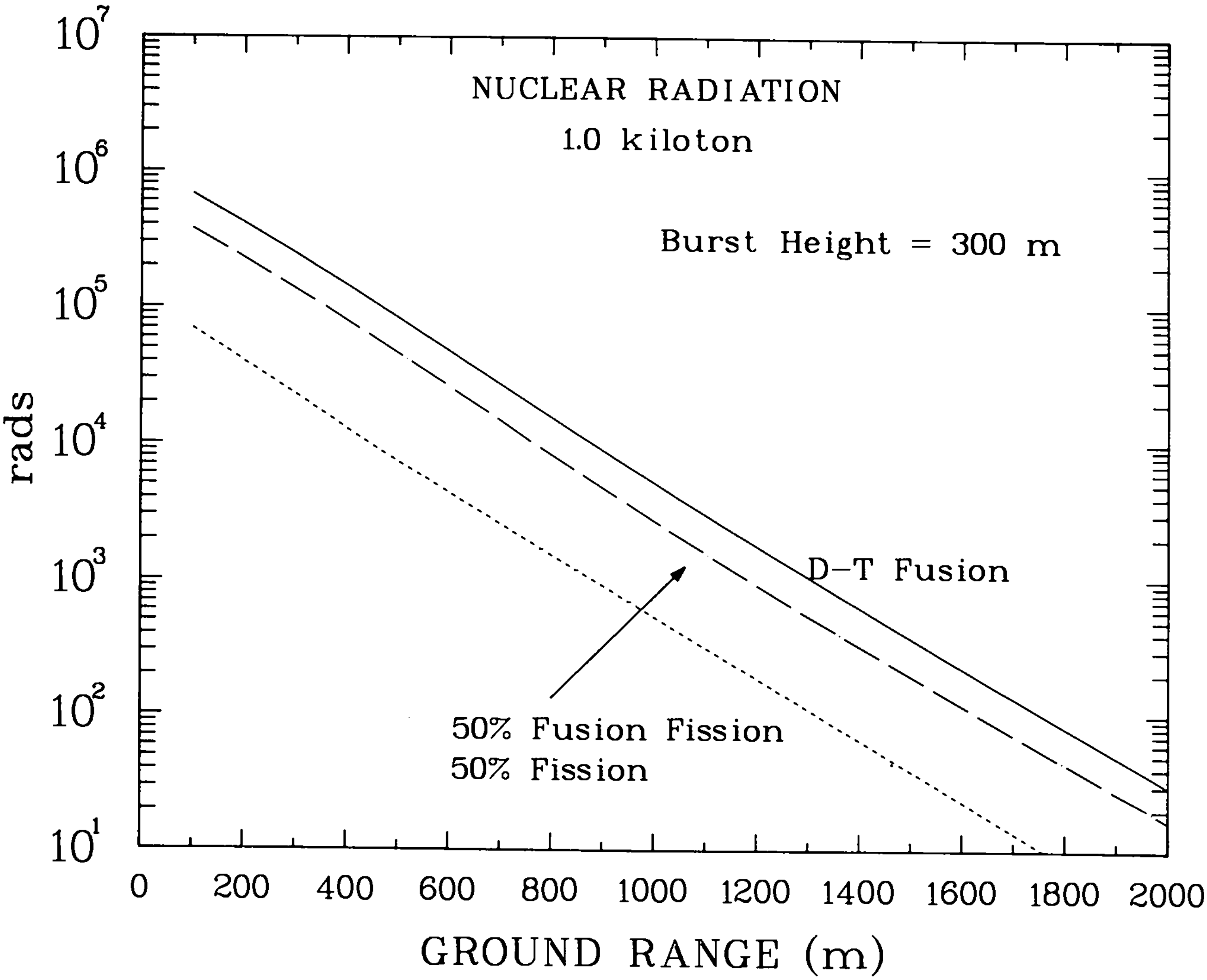

Fig. 24. Rads vs ground range for 1.0-kt fusion, fission, and fusion/fission (50/50) weapons. Burst height = 300 m.

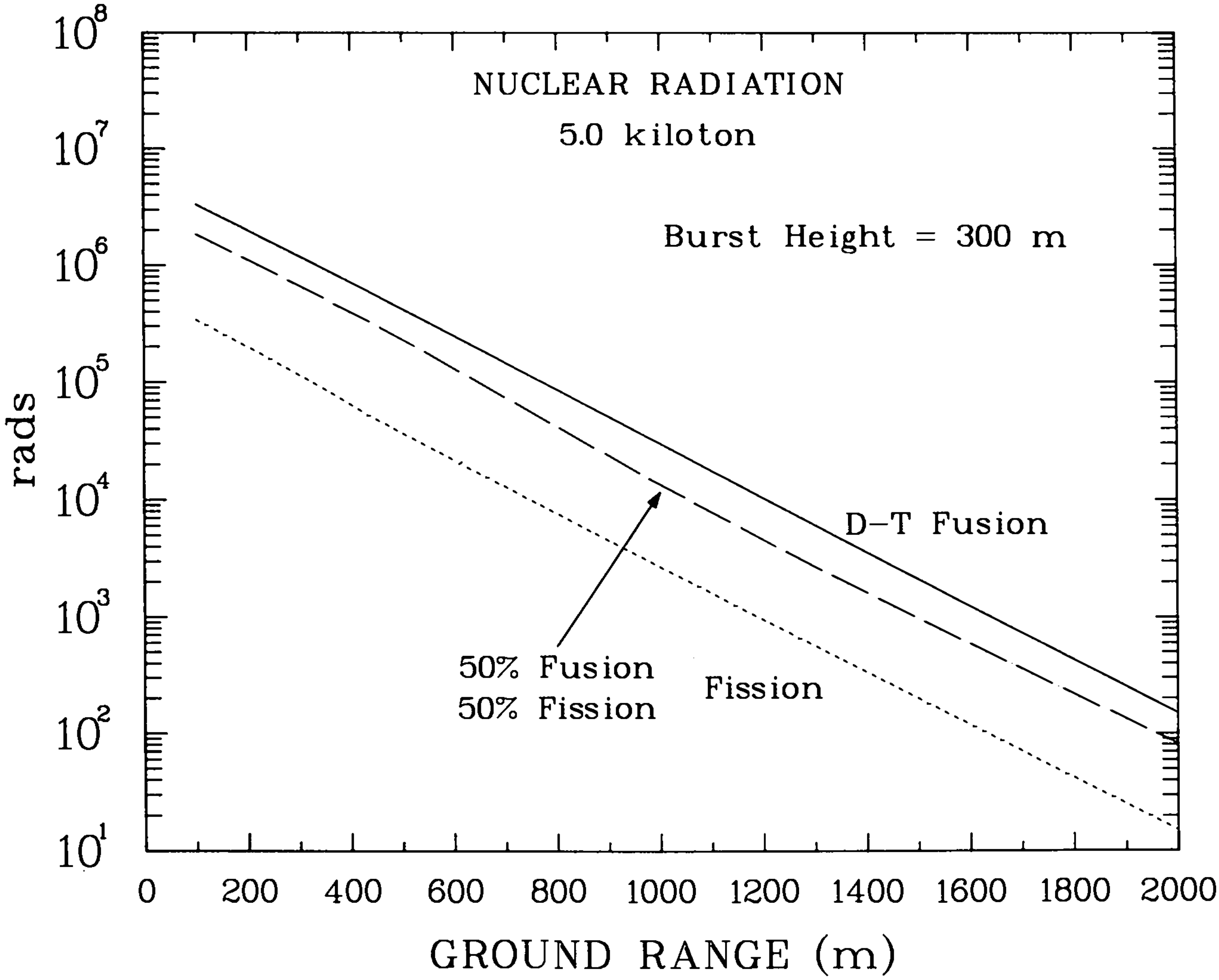

Fig. 25. Rads vs ground range for 5.0-kt fusion, fission, and fusion/fission (50/50) weapons. Burst height = 300 m.

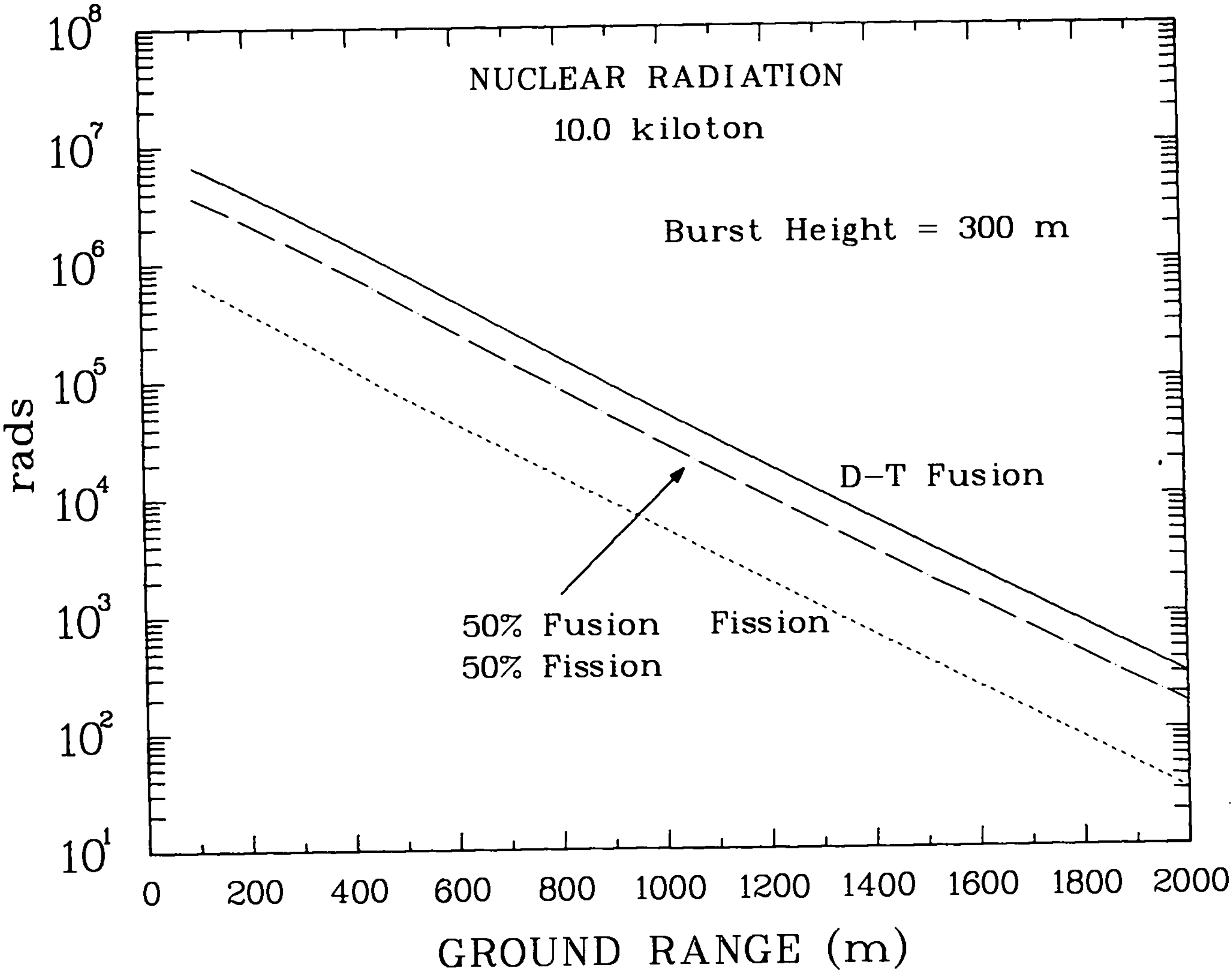

Fig. 26. Rads vs ground range for 10.0-kt fusion, fission, and fusion/fission (50/50) weapons. Burst height = 300 m.

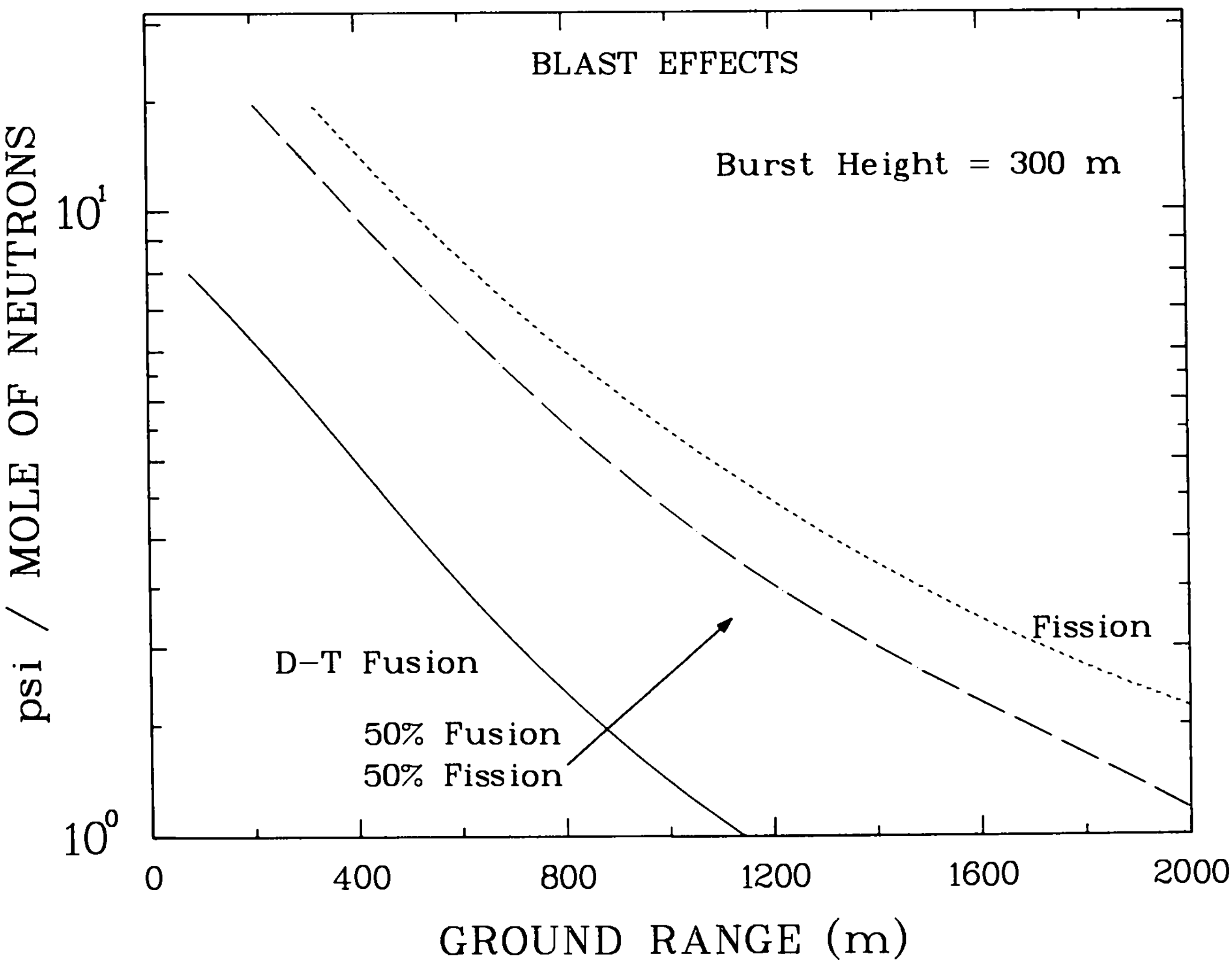

Fig. 27. Overpressure (psi) per mole of neutrons vs ground range. Burst height = 300 m. Fusion, fission, and fusion/fission (50/50) weapons.

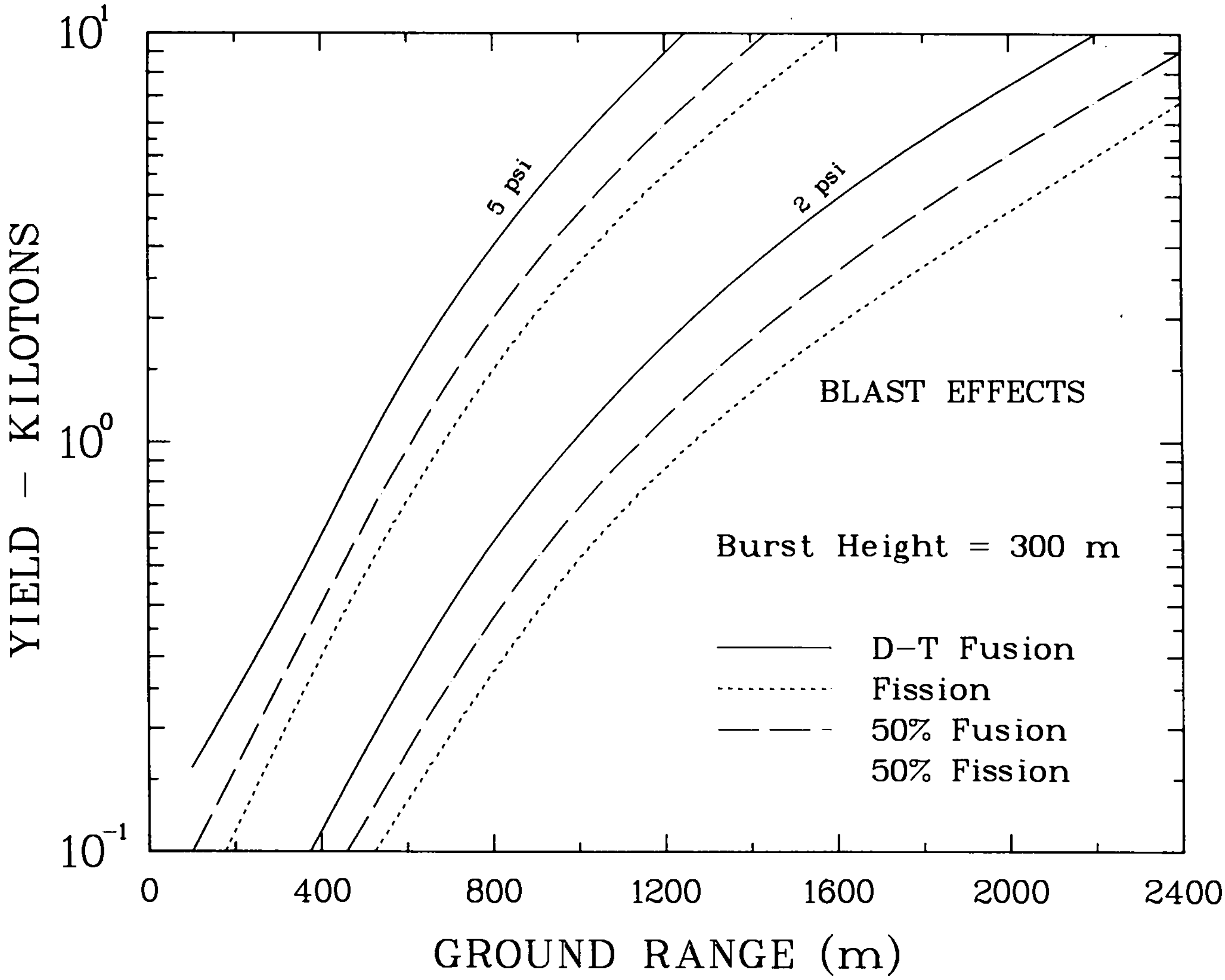

Fig. 28. Yield vs ground range for 2- and 5-psi overpressures. Burst height = 300 m. Fusion, fission, and fusion/fission (50/50) weapons.

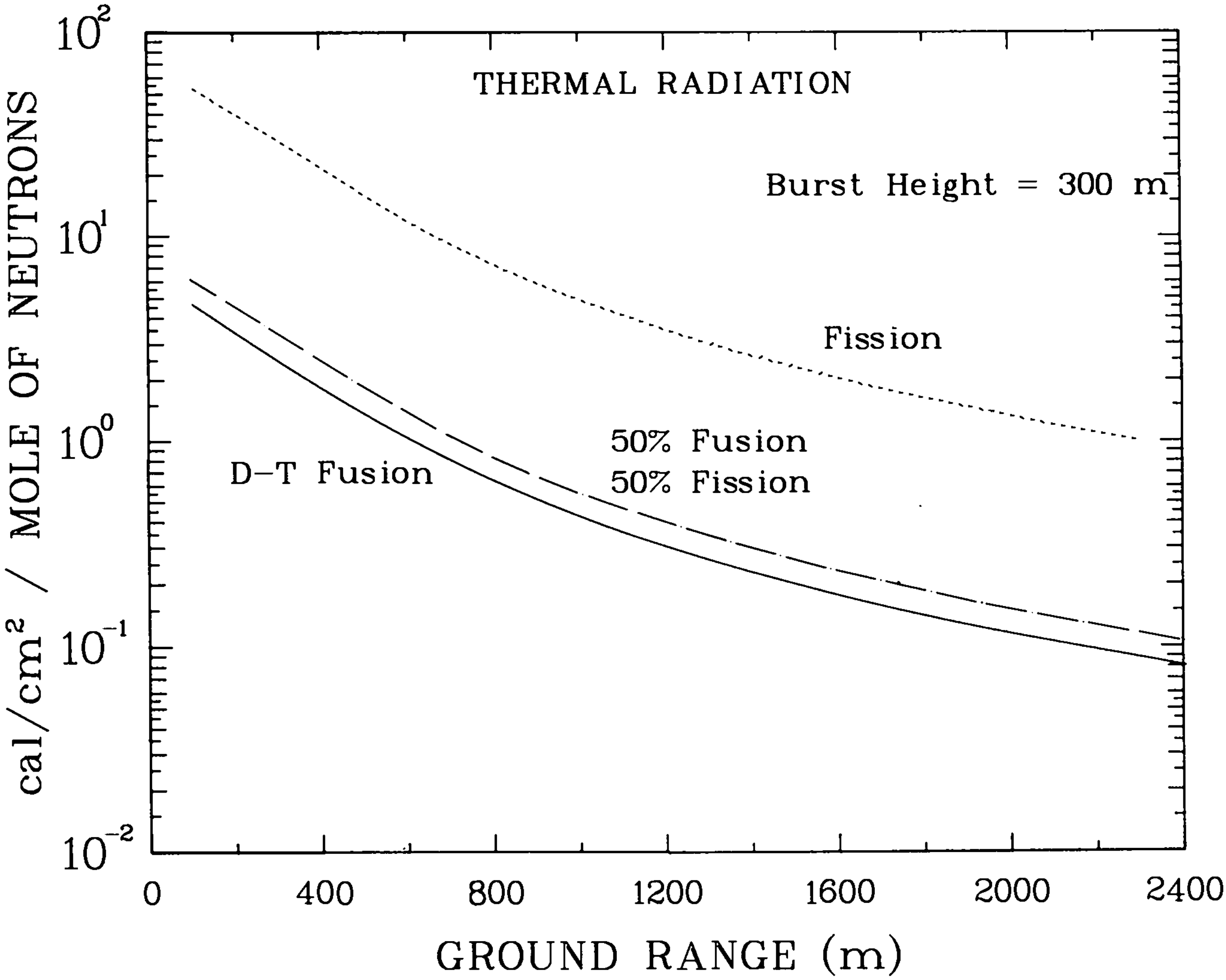

Fig. 29. Thermal radiation per mole of neutrons vs ground range. Burst height = 300 m. Fusion, fission, and fusion/fission (50/50) weapons.

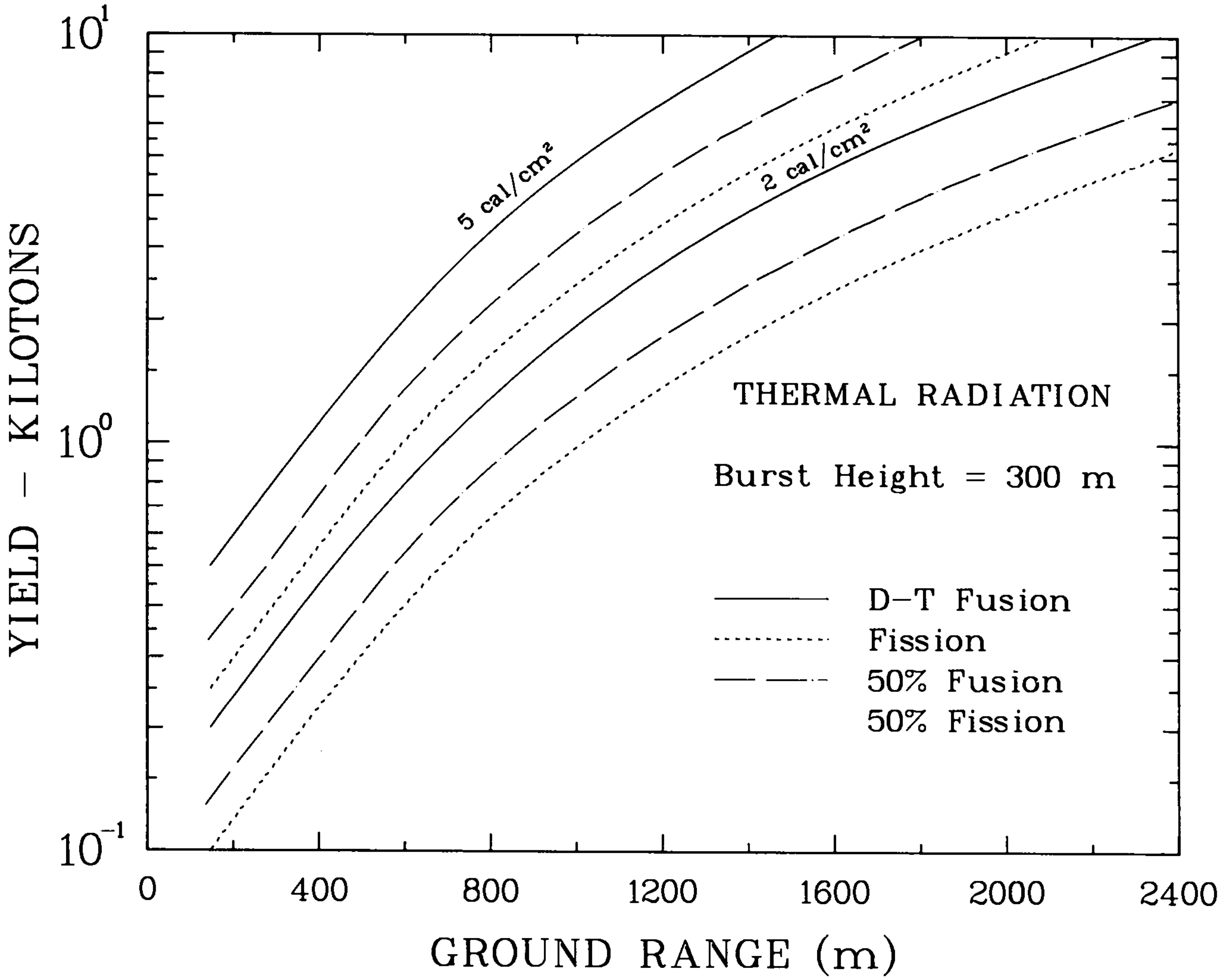

Fig. 30. Yield vs ground range for 2 and 5 cal/cm^2. Burst height = 300 m. Fusion, fission, and fusion/fission (50/50) weapons.

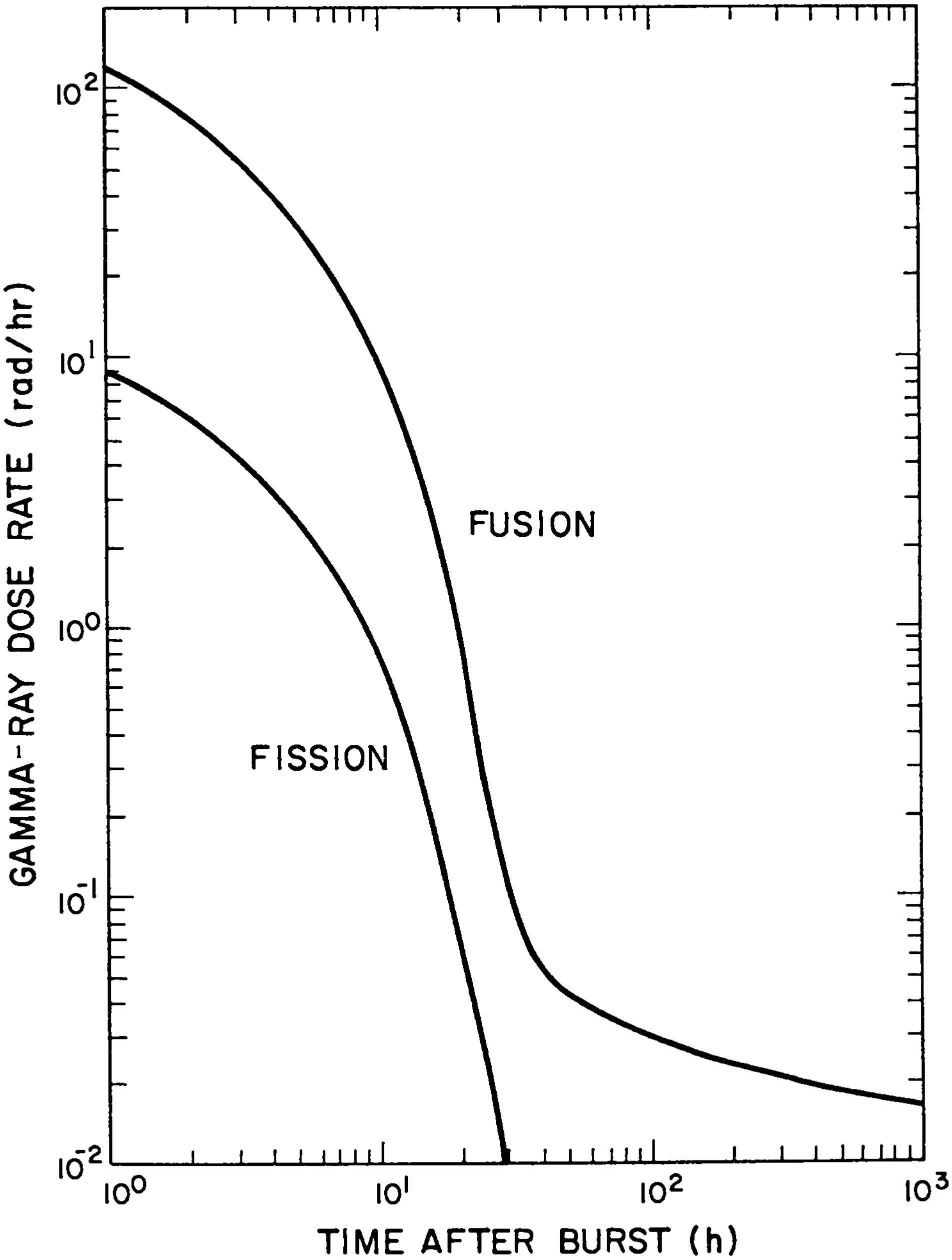

Fig. 31. Prompt neutron induced gamma-ray dose rate/kt at center of armor D-T fusion and fission.